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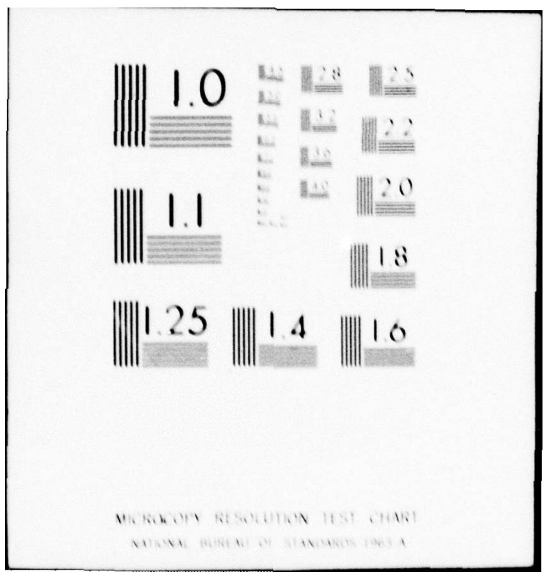
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USAF TERRESTRIAL ENERGY STUDY

Volume III, Part 2 — Energy Conversion Systems Handbook

BURNS & ROE, INC.
WOODBURY, NEW YORK

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Final Report – April 1976 - February 1978

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This report was prepared by Burns and Roe, Inc. to serve as a guide for the U.S. Air Force in selecting types of energy conversion systems to meet their future ground power requirements. The electric power requirements included in this report range from 10 kilowatts to 50 megawatts. Twenty-one types of systems, conventional as well as advanced, are considered. These include 19 types of energy conversion systems which utilize either chemical fuel, nuclear fuel, solar energy or wind energy and two types of energy storage systems

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which utilize electric power for recharging. Each system is characterized in terms of a set of economic, physical and performance parameters including acquisition costs, life cycle costs, size, efficiency and environmental constraints. A total of eighteen such parameters are presented for each type of system for several sets of requirements. The requirements are defined in terms of electric power level, voltage level, frequency and duration of operation corresponding to typical U.S. Air Force ground applications.

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Introduction

There are many types of energy conversion systems which can satisfy the wide variety of ground power requirements of the United States Air Force over the next three decades. These include conventional power systems which are currently being employed for ground power applications, as well as a number of advanced energy conversion systems which are currently undergoing research and development or are being utilized for special requirements such as space power applications. This report was prepared by Burns and Roe, Inc. to serve as a guide for the U. S. Air Force in selecting types of energy conversion systems to meet their future ground power requirements.

Twenty-one types of systems, conventional as well as advanced, are considered. These include nineteen types of energy conversion systems which utilize either chemical fuel, nuclear fuel, solar energy or wind energy and two types of energy storage systems which utilize electric power for recharging. Table I includes a list of the twenty-one types of systems and indicates the electric power levels considered for each type of system. The power levels range from 10 kilowatts to 50 Megawatts.

Each system is characterized in terms of a set of eighteen economic, physical and performance parameters. The economic parameters include acquisition cost, operating cost, maintenance cost and life cycle cost. The physical and performance parameters include size, weight, lifetime, efficiency, annual fuel consumption, start-up and shut-down times, reliability and rate of production of thermal energy as a by-product. Information is also provided on environmental constraints, location constraints, operational constraints and on the costs and time frames associated with development programs for advanced technology systems. Table II presents a list of the eighteen parameters. The definitions of the parameters are given in the Handbook Guide section of this volume which follows this introduction.

TABLE I

TYPES OF ENERGY CONVERSION SYSTEMS
AND CORRESPONDING ELECTRICAL POWER LEVELS

Energy Source	Energy Conversion System	ELECTRICAL POWER LEVELS					
		50 Mw	10 Mw	750 kw	250 kw	50 kw	10 kw
1) Chemical	Gas Turbine Generator (simple cycle)	X	X	X	X	X	X
2) Chemical	Gas Turbine Generator (regenerative)	X	X				
3) Chemical	Diesel Engine Generator		X	X	X	X	X
4) Chemical	Spark Ignition Engine Generator			X	X	X	X
5) Chemical	Fuel Cell - Phosphoric Acid	X	X	X	X	X	X
6) Chemical	Steam Turbine Generator (coal fired)	X	X	X			
7) Chemical	Steam Turbine Generator (oil/gas fired)	X	X				
8) Chemical	Stirling Engine Generator		X	X	X	X	X
9a) Chemical	MHD Generator	X	X				
9b) Chemical	MHD/Steam Generator	X					
10a) Chemical	Thermionic Generator			X	X	X	X
10b) Chemical	Thermionic/Steam Generator	X	X				
11) Nuclear	Steam Turbine Generator (PWR)	X					
12) Nuclear	Organic Vapor Turbine Generator			X	X	X	
13) Nuclear	Gas Turbine Generator (closed cycle)	X	X	X	X	X	
14) Radioisotope	Gas Turbine Generator (closed cycle)						X
15) Solar	Steam Turbine Generator	X	X				
16) Solar	Organic Vapor Turbine Generator			X	X	X	X
17) Solar	Gas Turbine Generator	X	X	X	X	X	X
18) Solar	Photovoltaic System	X	X	X	X	X	X
19) Wind	Wind Turbine Generator		X	X	X	X	X
20) External	Flywheel Storage	X	X			X	X
21) External	Battery Storage	X	X			X	X

TABLE 2

LIST OF PARAMETERS

Parameter 1.	Acquisition Cost (1977 dollars)
Parameter 2.	Life Cycle Cost (1977 dollars)
Parameter 3.	Lifetime
Parameter 4.	Volume/Size
Parameter 5.	Weight
Parameter 6.	Fuel
Parameter 7.	Environmental Constraints
Parameter 8.	Location Constraints
Parameter 9.	Operational Constraints
Parameter 10.	System Efficiency
Parameter 11.	Type of System
Parameter 12.	Start-up/Shut-down Times
Parameter 13.	Growth Potential
Parameter 14.	Reliability
Parameter 15.	Maintenance and Operation
Parameter 16.	Other Energy Production
Parameter 17.	Availability of Raw Building Materials
Parameter 18.	Development

All eighteen of these parameters are presented for each system for several sets of requirements. The requirements are defined in terms of electric power level, voltage level, frequency and duration of operation. There are seventeen sets of requirements as shown in Table III corresponding to typical U. S. Air Force ground power applications. For each system, data is presented only for selected sets of requirements which are considered to be appropriate for that system.

The report is presented in two volumes. Volume I is the Energy Conversion Systems Handbook and Volume II is the Summary Data Display. The Handbook is subdivided into 21 chapters, one chapter for each type of energy conversion system. Each Handbook chapter presents tables of the values of the parameters for each requirement considered to be appropriate for each system. The Summary Data Display is subdivided into 17 chapters, one chapter for each of the sets of electric power requirements. Each Summary Data Display chapter presents charts which graphically display the values of the parameters for each type of energy conversion system.

As indicated in Table I, the energy sources included in this report are chemical fuels including coal, natural gas, fuel oil, and other fuels derived from coal or petroleum, nuclear fuels employed in fission reactors or radioisotopic devices, solar energy and wind energy. Electrical power from an unspecified external source is also included as a source of energy for re-charging the energy storage systems. Several types of energy conversion systems are considered for each of the energy sources. The conventional energy conversion technologies considered for chemical fuels are the steam turbine, gas turbine (simple open cycle and regenerative open cycle), diesel engine and spark-ignition engine. Advanced technologies which are considered for chemical fuels are the fuel cell, Stirling engine, magnetohydrodynamics (MHD) and thermionic emission. Thermoelectric systems are not included since they are considered to be competitive only in size ranges well below the 10 kilowatt lower limit considered

TABLE 3

U.S. AIR FORCE GROUND POWER REQUIREMENTS INCLUDED IN REPORT

	Power Level	Operating Mode	Frequency/Phase	Voltage Level
1.	50 Mw	Continuous	60 Hz/3Ø	13.8 kv
2.	50 Mw	1 hour per day	60 Hz/3Ø	13.8 kv
3.	10 Mw	Continuous	60 Hz/3Ø	4160 V
4.	10 Mw	8 hours per day	60 Hz/3Ø	4160 V
5.	10 Mw	1 hour per day	60 Hz/3Ø	4160 V
6.	750 kw	Continuous	60 Hz/3Ø	4160 V
7.	250 kw	Continuous	60 Hz/3Ø	480 V
8.	50 kw	Continuous	60 Hz/3Ø	480 V
9.	50 kw	8 hours per day	60 Hz/3Ø	480 V
10.	50 kw	1 hour per day	60 Hz/3Ø	480 V
11.	10 kw	Continuous	DC	28 V
12.	10 kw	Continuous	60 Hz/3Ø	240 V
13.	10 kw	Continuous	60 Hz/1Ø	240 V
14.	10 kw	Continuous	60 Hz/1Ø	120 V
15.	10 kw	8 hours per day	DC	28 V
16.	10 kw	8 hours per day	60 Hz/3Ø	240 V
17.	10 kw	1 hour per day	60 Hz/3Ø	240 V

in this investigation. The types of systems considered in conjunction with nuclear fission reactors are the steam turbine, closed-cycle gas turbine and organic vapor turbine. The closed-cycle gas turbine is considered for use with the radioisotopic source. The types of systems considered for utilization of solar energy include a central-receiver/steam-turbine combination, a parabolic-trough/organic-vapor-turbine combination, a parabolic-dish/open-cycle air-turbine combination and photovoltaics. Other systems include the wind turbine, the storage battery and the flywheel. The last two systems are energy storage systems which must be periodically recharged from an external source of electric power.

As indicated in Table 3, the seventeen sets of power requirements are defined in terms of power level, voltage level, frequency (60 Hz or DC) and number of phases as well as duration of operation. Seven distinct power levels are considered, ranging from 10 kilowatts to 50 Megawatts. The three operating modes considered are continuous operation (for seventy percent of the hours in a year), eight hours per day, and one hour per day. The eight-hour and one-hour operations are considered to occur once each day for every day of the year.

For example, the first requirement listed is the 50 Mw continuous case. For this requirement, the system is designed to produce 50 Megawatts of electrical power and is assumed to operate continuously at full power at all times except for occasional periods when system is shut down for scheduled maintenance or when electrical power from the system is not required. For the purpose of determining the annual fuel consumption, the total number of hours of operation at full load is assumed to be 6132 hours per year (seventy percent of the total number of hours in one year). The electrical power is three-phase and is delivered at a frequency of 60 Hz and a voltage level of 13.8 kv. The second requirement listed is the 50 Mw one-hour case. This requirement differs from the first only in that the system is considered to operate one hour per day every day of the year. It is assumed that the system is started once each day, operates at rated power output for one hour and is then shut down. For the purpose of determining the annual fuel consumption, the number

of hours of operation is assumed to be 365 hours per year. The amount of fuel consumed during periods of start-up and shut-down is small and has therefore been neglected. The requirements which are designated as eight-hour cases are similar to the one-hour cases except that they operate for longer durations.

When a power system is to be selected for a particular USAF ground power application, the requirements of the system will have to be specified in greater detail than is indicated by the data in Table 3. For example, there may be restrictions associated with acceptable start-up times, space availability, siting constraints and so forth. Furthermore, each type of system has a number of design options so that the system selected can be tailored to a specific application. The values of the parameters given in this report (whether they be quantitative or qualitative values) represent systems which are typical for ground applications. However, since the design of a system can be tailored to a specific application, the values of the parameters may vary from one application to another. Thus the data presented are indicative of typical designs rather than being data precisely determined for specific pieces of hardware. In many instances, the data given are based upon an average of data obtained from several sources.

The original sources for the data presented in this report include recent publications, conference proceedings, manufacturers' literature and reports issued by government agencies, industrial organizations, research institutes and universities. Information was also obtained directly from manufacturers and other organizations by personal contact and by the use of questionnaires. In addition, internal Burns and Roe data sources were utilized for information on several types of systems and served as a basis for judging whether much of the data from other sources was realistic. Much of the original data available from the above sources did not correspond to the power levels specified in the U.S. Air Force list of requirements given in Table 3. It was therefore necessary to interpolate or extrapolate the existing data by the use of appropriate scaling laws or by graphical methods.

For each system, data is given in the Handbook only for selected power levels as shown in Table I. The power levels which are included for each system were selected on the basis of practical considerations. Power levels which can presently be met by conventional systems are obviously included for those systems. Power levels between the existing upper and lower power levels for conventional systems are also included for those systems. For several types of systems, both conventional and advanced, the higher power levels can be met by connecting several identical smaller units in parallel up to a practical maximum number of units. In some cases, the power level ranges of single units for conventional systems is extended to slightly below the present minimum or above the present maximum under the assumption that this can be achieved with a modest development program. The power levels considered for advanced systems are based upon stated goals for existing development programs for these systems. In some cases, power levels below and/or above the stated goals for advanced systems were considered if it appears to be practical.

SECTION II

HANDBOOK GUIDE

Each section of the Energy Conversion Systems Handbook covers one of the twenty-one types of energy conversion systems. Section 1.0 of each chapter gives a brief description of the system. Section 2.0 of each chapter indicates the requirements and time frames considered to be appropriate for the system. Section 3.0 of each chapter gives the values of each of the eighteen parameters. Section 4.0 of each chapter contains a list of references from which data was obtained for the system. This Handbook Guide has the same subdivisions and headings as each of the chapters which cover the energy conversion systems.

1.0 System Description

This section of each chapter of the Handbook includes a brief description of the system. The level of detail is sufficient only for identifying the particular configuration of the system for which the parameter values are given. Alternate configurations and design options are not discussed.

1.1 System Identification

This section of each chapter of the Handbook identifies the type of fuel converter considered (if there is more than one viable alternative), the type of energy conversion system (and the type of cycle employed where appropriate), the fuel considered and the working fluid for those types of systems for which there are viable alternatives and for which the choice of working fluid has a significant impact upon the values of the parameters. For systems which do not use fuel or for which there is only one viable type of fuel converter, the identification of type of fuel converter may be omitted. For systems which do not employ a working fluid or for which there is only one practical working fluid, the identification of the working fluid may be omitted.

1.2 System Definition

This section of each chapter of the Handbook includes a brief description and a simple schematic diagram of the system

which indicate the major components which are included in the estimates of the values of the parameters such as acquisition cost, weight, etc. An explanation of how the system works is not included.

1.3 Physical Description

This section of each chapter of the Handbook includes a pictorial representation of the system to convey information on the physical appearance and the relative size of the system. Several systems are available in a wide range of sizes. However, the pictorial representation is included only for one selected size. A brief description is included with each pictorial representation to identify the specific system and its power level.

2.0 List of Requirements and Time Frames

This section of each chapter of the Handbook contains a table which indicates the requirements and the time frames for which values of the parameters are provided in the subsequent sections of that chapter. The seventeen requirements are listed at the left side of the table. On the right side of the table are one or more columns with a calendar year indicated at the top of each column. For each requirement and for each designated calendar year, the table gives either an "X", and "N/A" or an "N/C". The "X" signifies that the corresponding requirement is included for the year specified at the top of the column. An "N/A" signifies that the requirement is considered "not applicable" for that particular year. The "N/C" signifies that "no changes" in parameter values are assumed relative to values indicated for an earlier date. Values of the parameters are included in subsequent sections of the chapters only for the combinations of requirements and dates which are designated by an "X".

The years designated above the columns in the Table in this section of each chapter refer to the years in which the systems are expected to be available. For systems which are currently available, the year 1977 is indicated. This would mean that such systems are either in common use or that such systems are not in common use but that an order can be placed with a manufacturer or group of manufacturers for a large number of identical systems. The number of systems is considered to be "large" if the costs of development and tooling are a small fraction of the total purchase price. For the latter case the technology base must have already reached the stage where the system has been demonstrated to work reliably and meet its designed performance specifications.

Several of the systems which are designated as being available in 1977 are expected to undergo improvements in technology which lead to changes in the values of several

of the parameters. For these cases, additional calendar years are designated which represent estimates of the dates when the technological advancements will have reached the demonstration stage and an order can be placed with a manufacturer or group of manufacturers for a large number of identical systems.

For systems which are considered to be advanced systems and are not currently available, one or more calendar years are designated above the columns in the table. The earliest year designated represents the calendar year when the technology base is first expected to reach the stage where the system can be demonstrated to work reliably and meet its designed performance specifications. The manufacturing technology base is also assumed to have reached a stage which would enable a manufacturer or group of manufacturers to produce the systems in a quantity which is sufficient to absorb the costs of development and tooling. Additional years designated represent years in which it is estimated that technological improvements will lead to substantial modifications of the values of some of the parameters.

3.0 Parameters

Data on the eighteen parameters is given in Sections 3.1 through 3.18 in each chapter of the Handbook. Each parameter is defined below.

3.1 Acquisition Cost

This section of each chapter of the Handbook includes a table which presents the estimated acquisition costs of the system for the designated requirements and time frames. All costs are given in 1977 dollars. The costs presented include the costs of all equipment and materials, the cost of installing or erecting the equipment at the site and the costs of any engineering work which is required to adapt a system to a particular site and to integrate the complete system if it is not available as a pre-packaged unit. The costs of foundations and site preparation are included as part of the acquisition cost but the cost of land procurement is excluded. Contingencies are included to cover uncertainties.

Price variations associated with differences in transportation costs of equipment delivered to and from various locations within the continent of North America are not included since the location of the site of utilization of the systems is not generally specified. However, there are two types of energy systems for which the acquisition cost is very sensitive to geographical location. These are the solar-powered systems and the wind-energy systems. The acquisition costs indicated for the solar-powered systems are specifically for a site in the southwestern area of the United States. The acquisition costs for solar-powered systems designed for the same performance will generally be different at other locations due to the variations in the intensity of solar radiation and weather conditions. The acquisition costs of the wind energy systems will vary with the location because of variations in mean wind speeds and wind consistency. Parameter data for

wind turbines is included for four distinct combinations of mean wind speed and wind consistency to provide a perspective on the dependency of the wind turbine system on geographical location and to indicate the upper and lower bounds on the acquisition costs and other parameters. The user of the Handbook will have to determine the solar energy and wind energy characteristics of the intended site and may, if necessary, modify the data given in this report in order to produce parameter values valid for that particular site. Appendix A includes figures which indicate approximate variations in solar energy and wind energy characteristics across the United States.

3.2 Life Cycle Cost

This section of each chapter of the Handbook includes a table which presents the estimated life cycle costs and average life cycle costs per year for the designated requirements and time frames. All costs are given in 1977 dollars. The life cycle cost for a system is the total cost incurred over the lifetime of the system. It is equal to the sum of the acquisition cost and the cumulative costs for fuel and operation and maintenance over the life of the system. For the battery and flywheel energy storage systems, the cost of electricity for recharging is included instead of fuel cost. The appropriate formula for determining the life cycle cost for each system is given in each chapter along with the tabulated data. The average life cycle cost per year is determined by dividing the life cycle cost by the expected lifetime of the system as given in Section 3.3 of each chapter of the Handbook.

The ground rules specified by the U.S. Air Force for this project do not include any factors to account for the cost of financing the procurement of an energy conversion system or the time value of money. Therefore, the acquisition cost is added directly to the cumulative costs for fuel and operation and maintenance to determine the life cycle cost. Should the user of the Handbook wish to account for interest payments on money borrowed at the beginning of a system lifetime, he should use a different method for determining the life cycle cost. Appendix B presents an alternate method for determinging life cycle costs which is more representative of the methods generally used by industry for making economic comparisons among alternatives.

Because of the differences in the estimated lifetimes of the various types of systems, the life cycle cost alone does not provide an adequate basis for comparison of systems. Therefore, the average life cycle cost per year is also tabulated. However, because of the escalation of the fuel costs, systems with longer lifetimes tend to have a greater average fuel cost per year than systems with shorter lifetimes. This may result in misleading conclusions if all factors are not taken into consideration. For example, if system "A" has a 15 year lifetime and system "B" has a 30 year lifetime, the fuel costs for the last 15 years of the life of system "B" would be very high and would have a significant impact on the life cycle cost per year of system "B" but not on system "A". However, if a particular application requires a 30-year total lifetime, it would be necessary to purchase two units of system "A" and only one unit of system "B". In this case, the impact of fuel cost escalation is the same for "A" and "B" and it is necessary to include the acquisition cost of system "A" twice in calculating its life cycle cost. The user of the Handbook would have to determine whether such a procedure is required for any particular application since this procedure was not employed for this report. Escalation of equipment costs would not be a factor since all costs are given in 1977 dollars.

Another result of the escalation of fuel costs is that the advanced systems which are not expected to begin operation until some future year show a greater average fuel cost per year than the conventional systems which begin operation in 1977. For example, if a conventional system beginning in 1977 and an advanced system beginning in 1985 both have the same fuel consumption rate and the same lifetime, the advanced system would still show a higher average fuel cost per year because the cost of the fuel per Btu would be higher in the later years. It may be more valid to compare an advanced system purchased in 1985 with a conventional system which is also purchased in 1985. In this case, the fuel costs for both systems would be based upon the same time periods. This would result in a life cycle cost for the earlier system which is higher than the life cycle cost given in the Handbook.

For many of the systems, parameter values are given for several different years to show the effect of technological advances. However, the impact of the technological advances on improvement in system efficiency is diminished by the impact of fuel cost escalation. For example, although the system efficiency of the open-cycle gas turbine (chemical-fuel/simple-cycle) increases from 1977 to 1985 and from 1985 to 1990, the life cycle cost of the system is indeed reduced from 1977 to 1985 but actually increases, in some cases, from 1985 to 1990 due to the higher cost of fuel for the system which begins operating in 1990.

3.3 Lifetime

This section of each chapter of the Handbook includes a table which indicates the estimated lifetime of the system for the designated requirements and time frames. The lifetime is expressed in years and represents an estimate of the number of years the system is expected to be able to produce its designed power output assuming that it operates either continuously (for seventy percent of the year) eight hours every day or one hour every day for the entire duration.

A distinction can be made between the actual lifetime of a system and the "design" lifetime. The actual lifetime is often difficult to predict since system components are subject to premature failure and the lifetime of the system itself is determined by a judgement which is made after a period of operation as to the continuing usefulness of the system for its specific application. Such a judgement involves external factors such as the existence of new alternative energy conversion systems (which had not originally been available) to meet the same requirements.

The "design" lifetime, on the other hand, can be specified as a characteristic of a system. It can be defined as the intended lifetime which is employed as a criterion for system design, component selection and maintenance schedules. If a long lifetime is desired, the system can be designed with large factors of safety, high quality components can be selected and an extensive maintenance program can be implemented. This has a significant impact on the acquisition cost and the maintenance cost. The maintenance cost includes the cost of equipment overhaul and replacement of parts. The estimated lifetimes indicated in the Tables of the Handbook are based upon common design and maintenance practice in the electric utility industry and industrial usage of electric power systems. The estimates of lifetimes of advanced systems are based upon similarities between advanced systems and comparable conventional systems. All acquisition costs and maintenance costs reflect the impact of the estimated design life upon these costs.

For the diesel engine generator and the spark-ignition engine generator, the estimated lifetimes are determined by multiplying the estimated time between major overhauls by the recommended number of major overhauls plus one additional period between overhauls. If this procedure results in an abnormally long lifetime, the number of overhaul periods is reduced accordingly. The maintenance cost is based upon the total costs of the overhauls as well as the costs for routine maintenance between overhauls.

3.4 Volume/Size

This section of each chapter of the Handbook includes a table which presents an estimate of either an area or a volume for the system for the designated requirements and time frames. For the systems which are considered to be fixed (as opposed to mobile or transportable, as defined in Section 3.11) it is normally the land area which is given by the table. Unless otherwise indicated, the land area includes the entire area within the boundary of the plant including the area required for fuel storage, cooling towers and all auxiliary components. It would not include any space which would be required for waste disposal. For some types of systems, such as wind turbines, multiple units are required to reach some of the high power levels. In such a case, the area specified includes the land area between each unit.

For other types of systems, the area which is given in the table is the area of the system's "footprint". In these cases, the table headings are labeled "area" instead of "land area". The footprint areas represent the area of the system envelope and indicate the amount of space required for transportation or installation of the system. Unless otherwise indicated, the footprint area does not include the area of fuel storage facilities for chemical fuels. For other systems, the tables indicate the system volume. This volume represents the volume of the system envelope and thus indicates the approximate amount of space which must be provided for transportation or installation of the system. Unless otherwise indicated, the volume does not include the volume of fuel storage facilities for chemical fuels. The relative proportions of the length and width or of the height, length and width are not given, but they can be estimated from the pictorial representations shown in Section 1.3 of each chapter.

The sizes indicated in the Handbook are based upon equipment which is designed for utility and industrial application.

In some cases, it may be possible to significantly reduce the size of a system to adapt it to an application for which compactness is a primary requirement. However, the acquisition cost and the values of some of the other parameters may be modified as a result. The extent to which size reductions can be made for each type of system and the associated modifications in the acquisition costs and the values of the other parameters are not given in the Handbook.

3.5 Weight

This section of each chapter of the Handbook includes a table which gives an estimate of the weight of the system for the designated requirements and time frames. However, the weights are not given for systems which must be erected at a fixed sight and which cannot be air lifted to provide ground power to remote sights. The weights which are given in the tables are for the total systems including auxiliary components, as defined in section 1.2 of each chapter unless otherwise indicated. For systems utilizing chemical fuels, the weight of the fuel or the fuel storage compartments are not included. For those types of systems for which the system can be broken down into modules for shipment, the weight of the largest such module is also given in the tables.

The weights which are given in the tables are based upon equipment which is designed for utility and industrial application. In some cases, it may be possible to significantly reduce the weight of a system to adapt it to an application where minimum weight is a primary requirement. However, the acquisition cost may increase and the values of the other parameters may also be modified as a result. The extent to which weight reductions can be made for each type of system and the magnitudes of the associated modifications in the acquisition costs and other parameters are not given in the Handbook.

3.6 Fuel

This section of each chapter of the Handbook includes a table which gives annual fuel consumption and average annual fuel cost for the system for the designated requirements and time frames. Information is also given on typical times between deliveries, fuels which may be substituted for the specified fuels and availability of the specified fuel. The annual fuel consumption is the amount of fuel consumed by the system in one year assuming that it operates either continuously for seventy percent of the year (6132 hours per year), eight hours per day every day of the year (2920 hours per year) or one hour per day every day of the year (365 hours per year). For chemical fuels, the amount of fuel consumed per year is given by the formula:

$$FA = \frac{3413 \times P \times H}{HV \times E}$$

where FA is the amount of fuel consumed per year in lbs. per year, P is the electrical power output in kw, HV is the fuel heating value in BTU per lb., H is the number of operating hours per year and E is the system efficiency expressed as a decimal fraction. For nuclear fuels, the amount consumed per year is given by a similar formula. However, the average amount of nuclear fuel which must be delivered to the plant each year also depends upon the percentage of the fuel which has undergone nuclear fission or radioactive decay at the time of refueling. For the cases in which the time between refuelings exceeds one year, the average amount of fuel delivered per year is equal to the amount of fuel delivered over the life of the system divided by the lifetime in years.

The fuel cost is given in 1977 dollars. It is assumed that fuel costs will increase at a faster rate than the general inflation rate. Appendix A given estimates of current fuel costs in terms of 1977 dollars per fuel BTU

as well as estimates of the rates of increase of fuel costs in future years. The future fuel costs are also expressed in terms of 1977 dollars. The fuel cost given in the tables in the Handbook chapters is the average fuel cost per year. It is determined by summing the fuel cost for each year over the life of the system and dividing by the system lifetime.

The amount of fuel consumed and its cost is not a relevant parameter for wind and solar-powered systems. However, the relative availability of solar and wind energy in various geographical locations is an important factor in determining the suitability of solar and wind-powered systems. Appendix A contains information on the geographical variations in energy which is potentially available from the wind and sun. The energy storage systems (batteries and flywheels) do not consume fuel directly. However, they do require electrical energy from an external source for re-charging. In order to make a valid comparison between energy storage systems and the other types of energy conversion systems, the cost of electricity is estimated for the energy storage systems. This is tabulated in Section 3.6 of the chapters for batteries and flywheels in place of the fuel cost for the designated requirements and time frames. The annual electricity cost includes a demand charge based upon the electrical power level (kw) of re-charging as well as an energy charge based upon the annual energy consumption (kw-hr per year). Appendix A gives estimates for current electricity cost and estimated rate of escalation of the cost of electricity. The annual cost of electricity is determined from the formula:

$$EC = DC + \frac{P \times H \times COE}{E}$$

where EC is the annual cost of electricity in 1977 dollars, DC is the annual electrical demand charge in 1977 dollars, P is the electrical power output in kw, H is the number of hours of operation per year, COE is the cost of electricity in 1977 dollars per kw-hr and E is the system efficiency.

Several of the Handbook chapters contain brief statements regarding the availability of the fuels specified for those systems. Several chapters also indicate alternate fuels which may be substituted for the specified fuels. Some of the alternate fuels can be used in place of the specified fuel with little or no modification to the system or its operation. Other alternate fuels require system modification or in some way alter the performance or cost of operation. Brief statements regarding the modifications or qualifications regarding the use of the substitute fuels are included in some of the chapters. However, the costs of any system modifications or changes in the values of any of the other parameters due to the use of a different fuel are not included.

3.7 Environmental Constraints

This section of each chapter of the Handbook includes a table which indicates the extent to which environmental factors influence the design and application of each type of system. However, no distinction is made between the various requirements and the various time frames. The information is presented in terms of symbols which express these environmental factors in a qualitative manner. There are three categories of factors for six types of environmental impact. The first category expresses the relative amounts of uncontrolled emission for each type of environmental impact. This refers to the emissions level which would occur if no pollution control equipment were installed and if no major modifications were incorporated into the design solely for the purpose of reducing emission levels or environmental impact.

The second category expresses the relative amount of control utilized to meet current regulations. It is assumed that each system must meet the current regulations established by the Federal Environmental Protection Agency (EPA). The control measures utilized include major design modifications to the system or installation of pollution control equipment for the purpose of meeting the regulations. The control measures also include any major restrictions on the application of each system such as limitations on the type or quality of the fuel which can be used. The acquisition cost data for each system reflects the cost of the pollution control measures. Since the pollution control measures required to meet EPA regulations may vary with the location of the site, typical measures are assumed.

The third category is the degree of difficulty which each system would have in meeting EPA regulations if the regulations were to become more stringent than they are at the present time. The degree of difficulty expresses the extent

to which additional design changes or more effective pollution control devices are required or the severity of the limitations on application of the system. It must be noted that none of the three categories is intended to indicate the extent to which a system is or is not a pollution source. Since each system meets current EPA regulations, all systems are, in effect, equivalent pollution sources. Furthermore, the user of this Handbook must be careful not to count the same thing twice by penalizing a system for requiring extensive pollution control equipment since the cost of the pollution control equipment is already included as part of the acquisition cost.

The four symbols -, 0, ◐ and ● are used to express the relative degree to which the design and application of each system is influenced by environmental factors for each of the three above categories. The symbol "-" denotes "none" and indicates no emissions for the first category, no control equipment for the second category or no difficulty in meeting more stringent requirements for the third category. Similarly, the symbol "0" denotes "minor", "◐" denotes "moderate" and "●" denotes "major".

The six types of environmental impact considered are thermal discharge, air pollution, noise, solid wastes, chemical discharges and radioactive wastes. Two types of thermal discharge are considered: (a) that which is emitted directly to the atmosphere (for example, the exhaust of a gas turbine engine) and (b) that which is emitted either to a body of water or to the atmosphere by means of a cooling tower. An example of a system with a type (b) thermal discharge is a nuclear, solar or fossil-fueled steam power plant. For each of these types of systems, the acquisition costs are based upon the use of a wet cooling tower.

Five categories of air pollution are considered: Carbon monoxide (CO), unburned hydrocarbons (HC), oxides of nitrogen

(NO_x), oxides of sulfur (SO_x) and particulate matter. In several types of systems, the emissions of these species can be controlled by adjustments in combustion processes with only minor impact on the acquisition cost or system efficiency. For other systems, there are restrictions in the constituency of the fuels utilized. If it is necessary to utilize other fuels, extensive pollution control equipment may be required.

Noise is not regulated by the EPA. However, there are local environmental regulations which restrict noise levels beyond the plant boundaries and there are limitations within the plant boundaries imposed by the Federal Occupational Safety and Health Administration (OSHA). The data reported in the Handbook is based upon the assumption that OSHA regulations and typical local environmental noise regulations are satisfied.

Solid wastes include dry wastes such as the fly ash which would be collected from a coal-fired power plant or undissolved wastes discharged in a water slurry such as bottom ash in a coal-fired power plant. For all systems in which a solid waste is produced, it is assumed that the wastes are transported off-site for disposal. Chemical wastes from power systems are most often associated with water treatment facilities. Power systems are not considered to be a major source of chemical wastes. Radioactive wastes include discharges to the atmosphere, radioactivity in condenser cooling water and reactor wastes. The data given in the Handbook on all environmental factors assumes normal plant operation.

3.8 Location Constraint

This section of each chapter of the Handbook includes a table which lists several location constraint categories and gives a qualitative estimate of the degree of difficulty of overcoming each category of location constraint by system re-design. There is no distinction made between the various requirements or the various time frames for this parameter. The categories listed pertain to the requirement of a water supply, manned operation of the system, fuel deliveries, solar insolation, wind speed, isolation from populated areas and an external supply of electrical power.

For some types of systems the need for water may represent a constraint which limits the use of those systems to sites where there is an adequate supply of water. Water may be required for cooling or for the process itself as in a steam power plant. The constraint of requiring water for cooling may be overcome in some cases by the use of a dry cooling tower. Some types of systems require that the system be manned at all times during operation or that operating personnel be in close proximity to the system. This limits selection of a site for such systems to areas where operating personnel can be stationed. This limitation can be overcome for some systems by installing an automatic control system.

For systems utilizing chemical fuels, the site is restricted to locations where periodic fuel delivery is practical. This constraint does not apply to nuclear, solar, wind or energy storage systems. The constraint category of dependency on adequate solar insolation refers to the fact that the power output and reliability of a solar power system depends strongly upon the geographical location of the system. Similarly, the constraint category of dependency upon adequate wind speed refers to the fact that the power output and reliability of a wind turbine depends strongly upon the geographical

location of the system. Data on the relative availability of solar and wind energy in various geographical locations within the U.S. are given in Appendix A. In some areas, nuclear power systems may be subject to constraints regarding the proximity of the systems to populated areas. The battery and flywheel energy storage systems must be located in areas where an acceptable supply of electrical power is available for recharging.

The qualitative symbols, —, O, ◐ and ● are employed to indicate an estimate of the degree of difficulty which would be experienced for each system in overcoming each location constraint. The symbol "—" indicates that essentially no difficulty would be encountered. The symbol "O" signifies minor difficulty while the symbol "◐" signifies major difficulty. The symbol "●" signifies an overriding difficulty and indicates that it is impossible or impractical to overcome the constraint.

For example, for the category of the requirement for manning the system during operation, the symbol " — " for a system would indicate that the system does not normally require manning during operation and can thus be considered for operation at sites where manned operation is not possible or not desired. The symbol "O" for a system would indicate that the system normally does require manning during operation but that it can be automated so that it can be operated unmanned in a remote location for an extended period of time. The symbol "◐" for a system would indicate that the system requires manning during operation and that, although automation is possible, it would be a major undertaking. The symbol "●" for a system would indicate that automation should not be considered and that the system should be considered only for sites where manned operation is acceptable.

No indication is given in the Handbook of the relative importance of each of the categories of location constraint relative to the other categories. The user of the Handbook data will have to evaluate the site which he is considering and determine which location constraints are important for his application.

3.9 Operational Constraints

This section of each chapter of the Handbook contains a table which lists several operating characteristics and gives a qualitative estimate of the effect which each category has on the performance of the system. No distinction is made between the various requirements and the various time frames for this parameter. The characteristics listed include efficiency reduction at part load, part load capability limitation, dependence on solar insolation, dependence on wind consistency, overload capacity limitations, delayed response to rapid load changes and life reduction from frequent rapid load changes.

Efficiency reduction at part load refers to the relative decrease in the efficiency of various types of systems when the electric power output is reduced to a level below the rated power level. Part load capability limitation refers to the relative extent to which the power output of various types of systems can be reduced below the rated power level under stable operating conditions.

Dependence upon solar insolation refers to the inability of a solar-power system to maintain rated power output after an extended period of cloud cover without a substantial capacity for storing energy. Dependence upon wind consistency refers to the inability of a wind-turbine system to maintain rated power output after an extended period of below-normal wind speeds without a substantial capacity for energy storage.

Overload capacity limitations refers to the relative capability of various types of systems to provide power in excess of the rated power level for short periods of time. Delayed response to rapid load changes refers to the relative differences to the rate of response of various systems to sudden changes in the power demand. Life

reduction from frequent rapid load changes refers to the relative susceptability of various types of systems to reduction of lifetime due to wear and fatigue associated with frequent rapid fluctions in power demand

The qualitative symbols -, 0, ◐ and ● are employed to indicate an estimate of the effect which each type of operating characteristic has on the performance of the system. The symbol "-" for a characteristic signifies that the characteristic is not observed for the system in question. The sumbols "0", "◐", or "●" for a characteristic signify that the effect of the characteristic on the performance of the system is either minor, moderate or major, respectively. The distinctions between minor, moderate and major are based upon the variations found in each characteristic for the various types of energy conversion system.

For example, the overload capacities of the systems considered in the Handbook range from zero to approximately 20 percent of the rated power level. The symbol ● is assigned to systems with zero overload capacity to indicate that overload capacity limitation has a major effect on system performance for these systems. The symbol - is assigned to systems with overload capacities in the vicinity of 20 percent to indicate that overload capacity limitation has the least detrimental effect on system performance for these systems. The symbols 0 and ◐ are assigned to systems with overload capacities in the vicinities of 10 percent and 5 percent, respectively. However, these percentages are not to be considered to be precise values since the overload capacity for any type of system can vary over a considerable range as the design of the system is varied. The symbols assigned in the Handbook are based upon common design practices.

Other operating characteristics are treated in a similar manner and the impact of each characteristic on system

performance can be modified to some extent by altering the system design. No attempt is made to indicate the importance of the characteristics relative to each other. The ranking of the characteristics is dependent upon the intended application. The user of the Handbook would be required to assess the importance of each characteristic for his specific application.

3.10 System Efficiency

This Section of each chapter of this Handbook includes a table which gives the efficiency of the system for the designated requirements and time frames. The system efficiency applies to the total system, including auxiliary equipment. For chemical and nuclear-fueled systems, the system efficiency is defined as the net electrical power output divided by the rate of energy input in the form of fuel. For energy storage systems and for solar and wind energy systems which utilize energy storage, the duration over which the energy is input to the system may differ from the duration over which the energy output occurs. For these types of systems, the system efficiency is defined as the net electrical energy output divided by the energy input in the form of solar energy, wind energy or electrical energy from an external source.

The net electrical output is defined as the electrical energy or power available to perform the function for which the system is designed. Electrical power required to run auxiliary equipment which is part of the power system is not included as part of the net output. The energy input is defined as the energy input in its basic form. For chemical fuels, the rate of energy input is equal to the fuel consumption rate times the higher heating value of the fuel. For systems which require a fuel processor or reformer, the energy input is considered to be the energy of the fuel entering the processor or the reformer. For solar powered systems, the energy input is the radiative energy associated with the solar insolation incident upon the area of the solar collector. For Wind Turbines, the energy input is the kinetic energy associated with the wind stream which intersects the cross-sectional area of the wind turbine blades.

Efficiencies for various types of systems can vary with the design of the system, with the fuel utilized or with

the mode of operation. The efficiencies indicated in the Handbook are based upon equipment which is designed for utility or industrial application utilizing the specified fuel and operating at rated power level.

3.11 <u>Type of System</u>

This Section of each chapter of the Handbook contains a table which indicates whether the system is mobile, transportable or fixed for each of the designated requirements. Installation times are also indicated in the table. Standard U. S. Air Force definitions are applied to determine the system type. A system is considered to be mobile if it is transportable by truck or aircraft, can be assembled or dismantled within an eight-hour period and requires no prior site preparation. A system is considered to be transportable (but not mobile) if it can be transported as broken-down packages, can be set up or removed within a one-week period and requires only minor site preparation. A system is considered to be fixed if it does not meet the above requirements for mobility or transportability. There is no limit on the time period over which a fixed system can be set up or removed and extensive site preparation may be required.

For a system to be considered mobile or transportable, the system itself, or the largest package if it can be broken down, must meet certain size and weight restrictions for transportation by truck or airplane. The standard U. S. Air Force maximum dimensions for road transportability are 10 feet wide by 13 feet high by 60 feet long. The standard U. S. Air Force maximum dimensions for transportation by air are 16 feet wide by 9 feet high by 100 feet long. In addition, there is a maximum limit of 350 lbs per square foot floor loading for aircraft.

Installation time or construction time is also indicated in the table in this section of each chapter. The term installation time is applicable to systems which can be delivered as a complete package to a site. The installation time then refers to the time required to prepare the site, set-up the system and prepare for initial operation. The term construction time is applicable to fixed systems

which cannot be provided as a complete package from a single manufacturer. These systems normally have to be custom designed to fit the site conditions and are composed of many components from different manufacturers. All parts are not usually delivered simultaneously.

3.12 Start-Up /Shut-Down Times

This section of each chapter of the Handbook contains a table which gives estimates of the start-up times and the shut-down times for the systems for the designated requirements and time frames. A distinction is usually made between "cold-start" and "hot-start" as two starting modes. The tabulated times correspond to the "cold-start" mode and refer to the time required to bring a system from a ready-to-start condition to full-power operation. On the other hand, the hot-start time period (not tabulated) would refer to the time required to reach full power output from a condition in which the system is essentially in operation but is not producing any net power.

For systems which include thermal storage, such as the solar/steam and solar/organic cycles, the cold-start time is appropriate only for the initial start-up. For subsequent daily operation the thermal storage system is assumed to be able to considerably reduce the start-up times.

There are also multiple definitions of shut-down time. The shut-down time given in the table corresponds to the shut-down mode which is comparable to the cold-start mode upon which the start-up time is based. For example, for many systems, the factor which determines the minimum start-up and shut-down times is thermal stress. Thus, although the power output can be shut-off very rapidly, the system often cannot be cooled down rapidly without resultant damage due to thermal stresses.

Like many of the other parameters, the start-up and shut-down times for any system can be modified by design alterations with consequent modifications in the values of the other parameters. The times indicated in the tables are based upon equipment which is designed for utility and industrial application.

3.13 Growth Potential

In this section of each chapter of the Handbook, the extent to which each system has growth potential is indicated. Growth potential refers to the capability of an installed system to increase its rated power output in small increments by the addition of modular segments to the original system. This does not include power-boosting auxiliary components such as turbochargers. An expample of a system which does have growth potential is the fuel cell. The fuel cell is comprised of a large number of modular elements. The capacity of the fuel cell can be increased in small or large increments by the installation of one or more additional modular elements which are identical to the modular elements of the original system. Certain portions of the fuel cell system, such as the fuel reformers, may or may not be composed of modular elements, however. Thus, to have complete flexibility for growth potential, the fuel reformers would either have to be over-designed to allow for increased capacity or they themselves would have to be designed to have growth potential. A gas turbine, on the other hand, is considered to have no growth potential since the capacity of a gas-turbine installation can be increased only by adding another gas turbine. Thus, the key to growth potential is modular construction of the system.

Four categories of growth potential are considered. The first category is that of a fully modularized system in which the major portion of the system is modularized and only the auxiliary components are non-modularized. This category has the greatest growth potential. The second category includes systems in which the main energy converter is modular but in which one or more major components are inherently non-modular. An example of a system in this category is the thermionic generator.

The therminonic converters are modular but the combustor would not be modular in its optimum configuration.

The third category includes systems which may be considered to be modular by default. An example is a system which is available in single units up to a maximum size of, say 1 Mw. A 10 Mw system can be set up by installing 10 one Mw units. Thus, the 10 Mw system is modularized not because of the inherent nature of the system, but because multiple units had to be ganged together due to size limitations on the single unit. For systems in this category, the extent to which the system has growth potential depends upon the power level required. The fourth category consists of those systems which are not modular and therefore have no growth potential.

3.14 Reliability

This section of each chapter of the Handbook contains a table which lists several factors which effect system reliability and gives a qualitative estimate of the extent to which each factor affects the reliability of the system. No distinction is made between the various requirements and the various time frames for this parameter. The factors include numerous moving parts, high temperature operation, high stress levels, high radiation levels, corrosive attack, thermal cycling, non-modular design, solar insolation required and wind required.

The number of moving parts in a system has an impact on system reliability, but more important than the number is the extent to which such moving parts are critical to the functioning of the system and the extent to which they are subject to failure. High temperature is another factor which impacts reliability, but the temperature has to be considered in relation to the materials which are exposed to the high temperatures. High stress levels can lead to failure, but again, consideration must be given to the materials which are subject to the high stresses in order to assess effect which stress levels have on reliability.

Radiation can cause material modifications which can lead to deterioration of strength. Corrosive attack occurs to some extent in nearly all types of systems. However, in the present context, it is only those cases in which corrosive attack can lead to system failure which are of interest. Thermal cycling can have an impact on reliability if the extent of the thermal stresses are significant and if the materials which undergo thermal cycling are stressed to the limits of their capability.

Non-modular design in itself does not lead to unreliability. However, modular construction of systems can

result in higher reliability if failure of one or several modules does not lead to complete failure of the system. The requirement for solar insolation refers to the loss of reliability which a solar-power system suffers following a long period of cloud cover which drains the capacity of the storage system to the point where the system is not able to maintain the required power level. The requirement for wind refers to a similar loss in reliability of a wind-turbine system following an extended period of below-normal wind speed.

The qualitative symbols -, 0, ◐, ● are employed to indicate an estimate of the effect which each of the above factors has on the reliability of the system. The symbol "-" for a factor or condition indicates that the condition does not exist for the system in question. The symbol "0" for a factor or condition indicates that the condition does exist but that it has only a minor effect on the reliability of the system. The symbol "◐" for a factor or condition indicates that the factor has a moderate effect on the system reliability while the symbol "●" denotes that the factor has a major effect.

For example for the factor "high temperature levels", the symbol "-" for a system would indicate that the temperatures which occur in the system are not high relative to the temperatures which would result in significant reductions in the strength of the materials of construction. The symbol "0" for a system would indicate that high temperatures may exist which would reduce the strength of materials exposed to those temperatures but that the strength reductions or the stresses to which those materials are subjected are not sufficient to cause failure. The symbol "◐" for a system would indicate that the peak temperatures

occurring in a system are sufficient to reduce the strength of materials which are exposed to those temperatures and may occasionally lead to systems failure. The symbol "●" for a system would indicate that strength reductions of materials due to high temperatures are severe and that this is one of the major causes of failure for this system.

3.15 Maintenance and Operation

This section of each chapter of the Handbook includes a table which presents an estimate of the operating and maintenance costs per year for each system in 1977 dollars for the designated requirements and time frames. For several systems, the operating and maintenance costs are listed separately. For other systems, the operating and maintenance costs are combined into one number. The table also indicates for each requirement whether or not operating personnel are continuously required to be in attendance while the system is operating. Several of the chapters give data on the duration of overhaul periods and some chapters indicate whether the overhaul is normally performed on-site or if the system must be transported to an off-site location for overhaul.

The operating costs include the costs of labor and materials required for operating the system. The maintenance costs include the costs of labor and materials for routine maintenance as well as for periodic overhauls. Since the annual operating and maintenance cost may vary from year to year, the average O&M cost is determined by summing the O&M costs over the life of the system and dividing by the system lifetime.

For conventional systems, the operating and maintenance costs are based upon data obtained from both manufacturers and users of equipment in industry and the utilities. For advanced systems, O&M costs are estimated from O&M costs for similar conventional systems with contingencies added for uncertainties.

3.16 Other Energy Production

This Section of each chapter of the Handbook includes a table which indicates the approximate amount of waste heat which may be recoverable from the system for utilization for various purposes. The table gives the thermal energy recoverable in units of Btu per hour as well as in kw-thermal for the designated requirements and time frames. The recoverable waste heat magnitude indicated in the tables is 60 percent of the total thermal discharge of the system under full power operation. The formula for determining these magnitudes is

$$RWH = 0.6 \times \frac{Px\ (1-E)}{E}$$

where RWH is the recoverable waste heat in kw-thermal, P is the electrical power output in kw-electrical and E is the system efficiency as given in Section 3.10 of each chapter. This formula is based upon the assumption that 60 percent of the total thermal discharge can be recovered for utilization. This percentage can vary from application to application since it depends upon the manner in which the thermal energy is utilized and upon the equipment used for recovery of the thermal discharge.

The suitability of the recoverable waste heat for utilization varies greatly from system to system and also depends upon the particular application for which the waste heat is being considered. The thermal discharge can be in the form of a gaseous or liquid effluent; it can be concentrated or dispersed; and its temperature level can vary over a wide range. For several types of systems, there may be more than one source of thermal discharge simultaneously.

This section of each Handbook chapter also indicates the source of thermal discharge for each system and indicates the type of thermal energy distribution system for which the temperature level of the source is suitable. Typical types of thermal energy distribution systems are low pressure hot water, high pressure hot water, saturated steam and superheated steam. The temperature at which the thermal discharge can be utilized depends upon the effectiveness of the heat exchanger which transfers the thermal discharge from the source to the utilization distribution system.

There is a considerable amount of variability and flexibility associated with the waste heat recovery from any given system. For a system whose primary function is to produce electricity, the electrical output is maximum under conditions which minimize the temperature of the thermal discharge or discharges. However, for applications in which utilization of recoverable waste heat is very important, the design and operation of the system can be modified to yield higher temperature thermal discharge. The resultant electric power level will, however, be reduced.

3.17 Availability of Raw Building Materials

This Section of each chapter of the Handbook indicates whether or not each system requires any materials which may not be readily available in sufficient quantity to allow the system to be produced in large quantities. The criterion utilized for identifying critical materials is that the system require materials which are of limited supply in this country and that the quantity of these materials required by the system be sufficiently large that a limit is placed upon the number of systems which could be produced in the U.S. All materials which are considered to meet this criterion are identified.

3.18 Development

This Section of each chapter of the Handbook indicates whether the system requires a development program and includes a table of the estimated costs and time periods of the development programs for those systems which require development. The development costs are expressed in 1977 dollars and represent the cumulative costs over the specified time period. The time period is expressed in years and represents the estimated time required to develop the system under an accelerated program.

The systems for which this data is presented include advanced systems, conventional systems whose performance can be significantly improved by further development and conventional systems which are available in some size ranges but for which further development would be required to extend their availability to the size ranges included in this report. The development programs would advance the technology of the system from the current state-of-the-art to the point where a prototype has been successfully demonstrated. The development program does not include the establishment of an industry to manufacture the systems in large quantities.

The estimates of development program costs and durations are based upon existing budgets and schedules for current programs sponsored by government agencies, industry or institutions. Allowance is made for program delays for systems which require extensive advancement beyond current technology. Adjustments are also made for development of complete integrated systems where existing development programs are concentrating primarily on individual major components. Several of the chapters also present information on existing development programs, indicating what agencies or organizations are involved and indicating what improvements are required.

4.0 REFERENCES

This Section of each chapter of the Handbook includes a list of references from which much of the data presented in each chapter was obtained.

SECTION III

GAS TURBINE GENERATOR - SIMPLE CYCLE

(CHEMICAL FUEL)

1.0 SYSTEM DESCRIPTION

1.1 System Identification

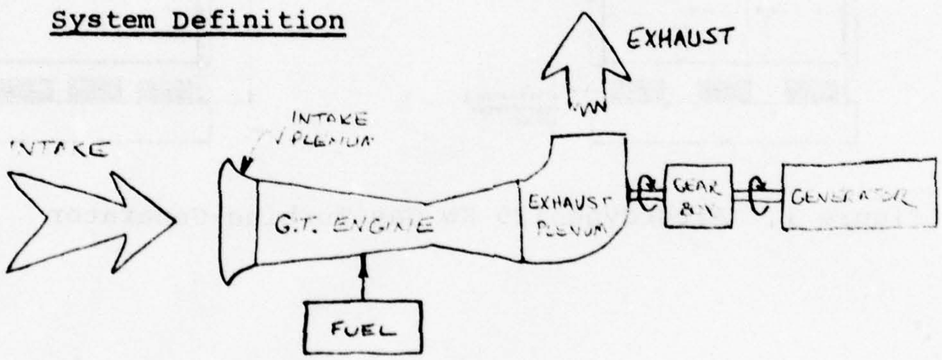
Energy Converter/Cycle - combustion gas turbine/open brayton simple cycle (non-regenerative)

Fuel - No. 2 distillate oil

Working Fluid - air (once through)

Equivalent Alternate Types - natural gas

1.2 System Definition



The major components of the power system consist of the combustion turbine (gas turbine) prime mover, gearbox (for requirements of 10 Mw and below), generator, control system, fuel system (including five-day capacity storage tank for requirements of 750 kw and below and two-week capacity storage tank for requirements of 10 Mw and above), intake plenum and air filter, and exhaust plenum and ducting.

1.3 Physical Description

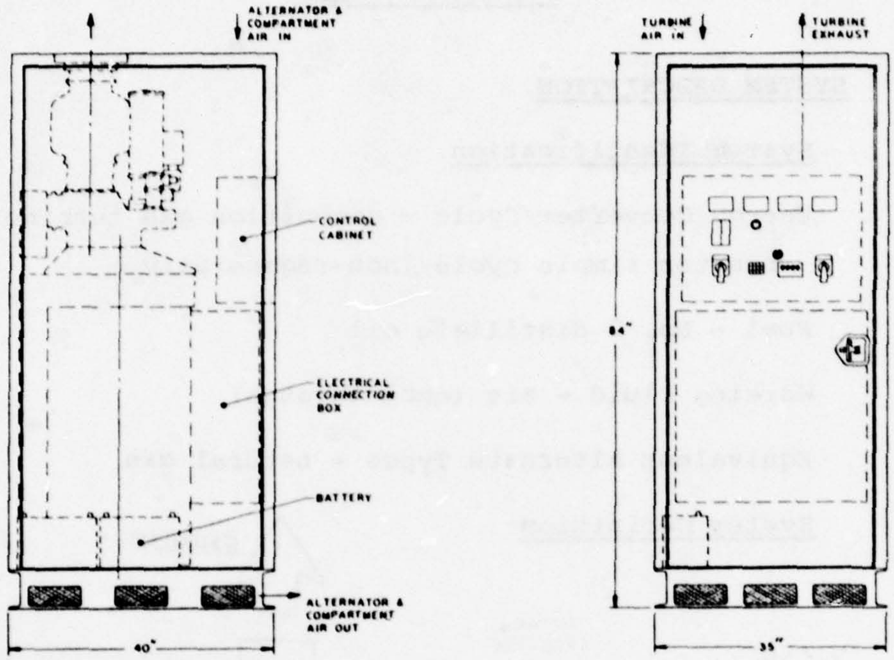


Figure 1. Alturdyne 125 KW Gas Turbine-Generator

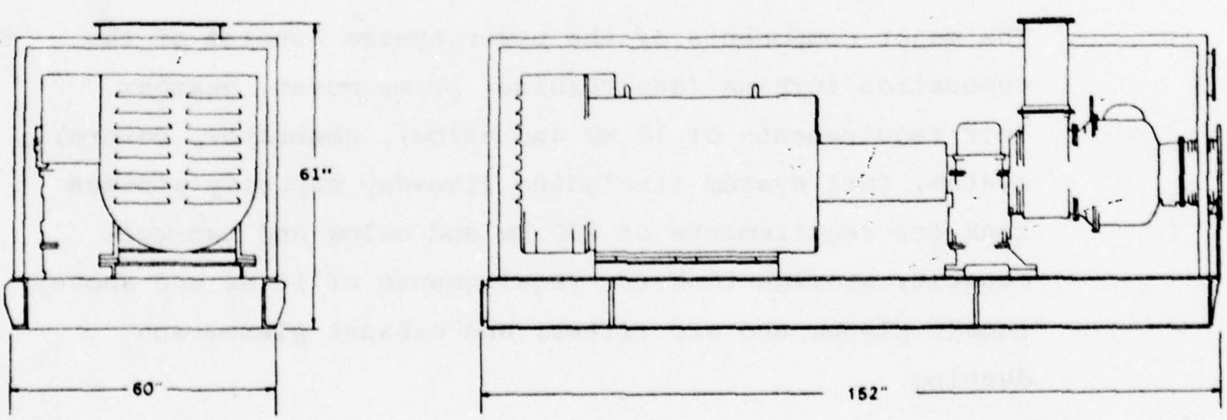
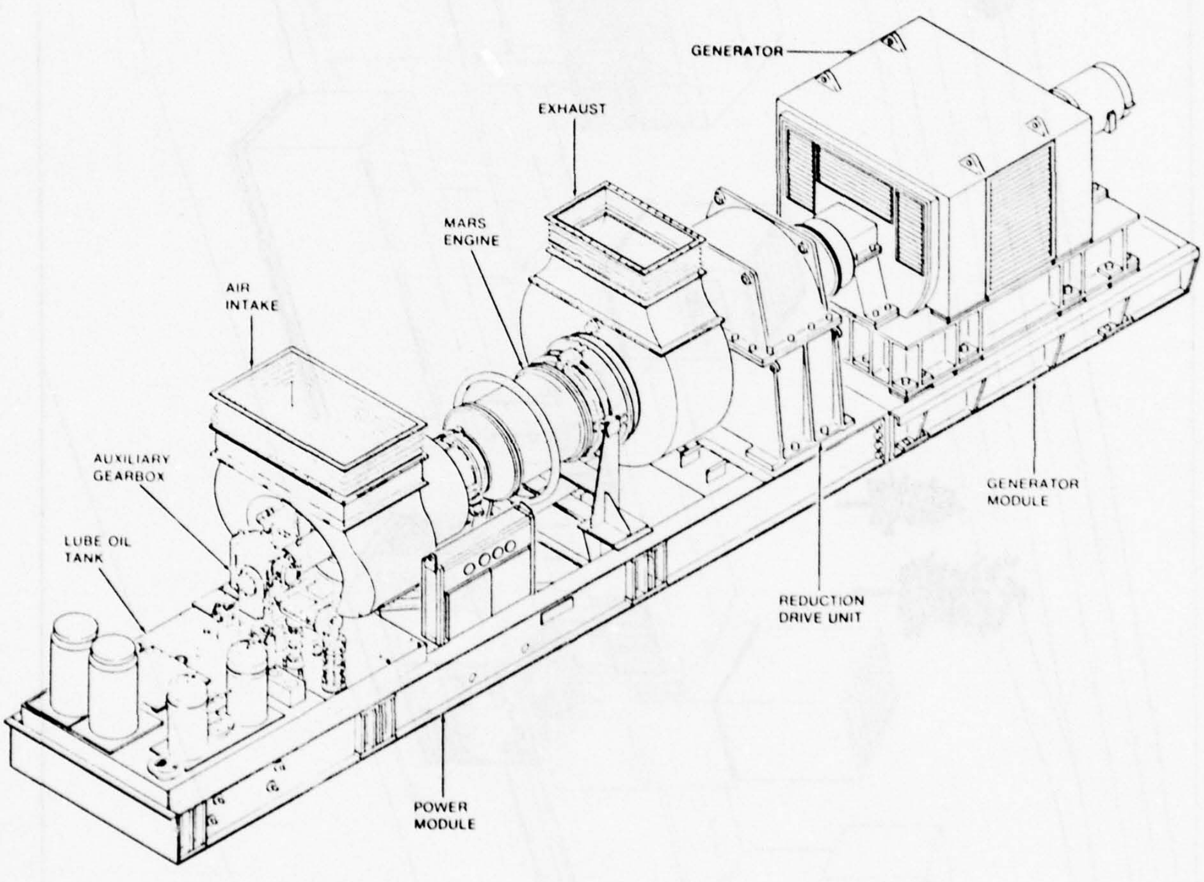


Figure 2. Stewart & Stevenson 500 KW Gas Turbine-Generator

Figure 3.



SOLAR 7 MW GAS TURBINE-GENERATOR

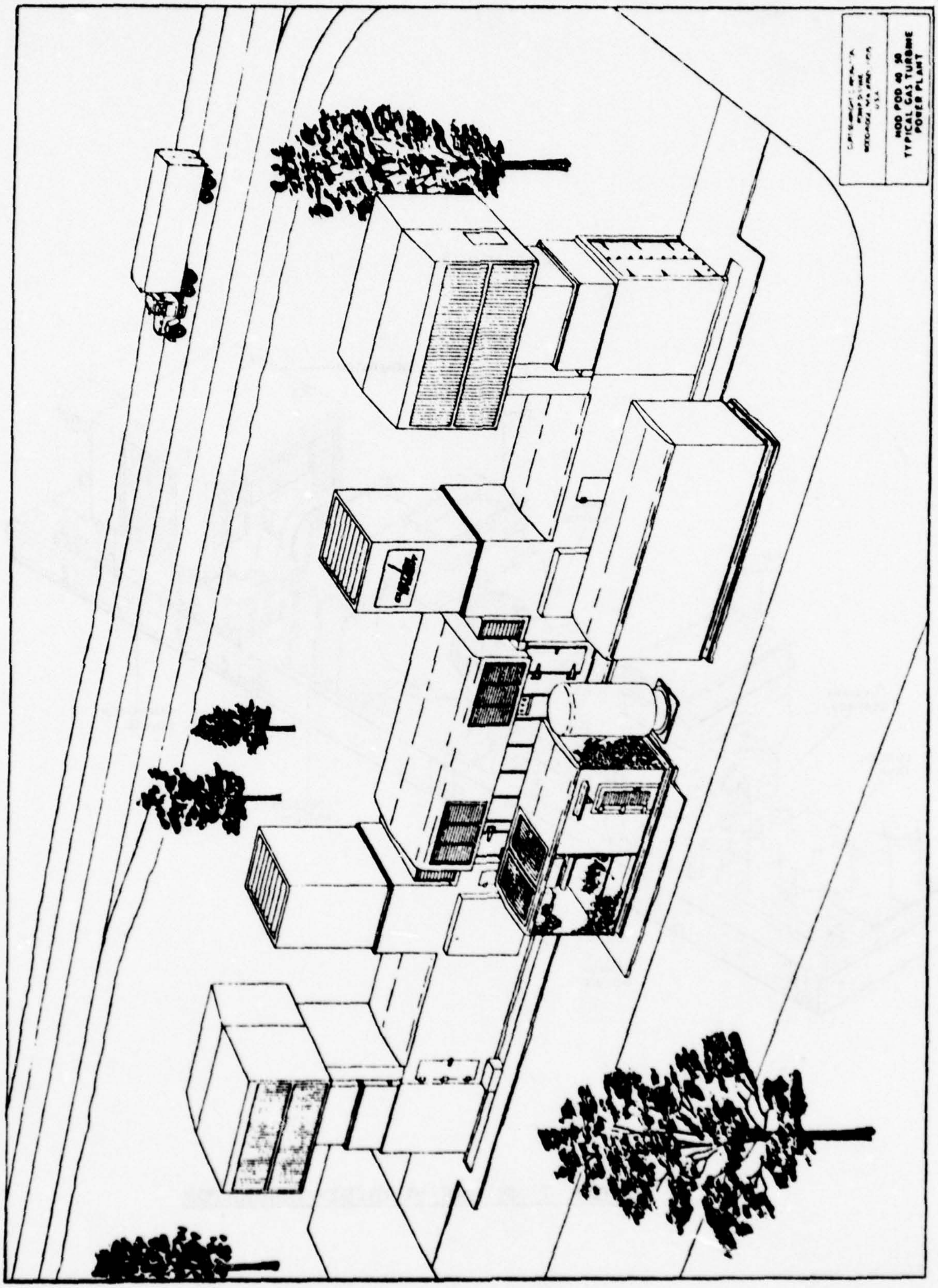


Figure 4. Curtiss-Wright 50 MW Gas Turbine Power Plant

2.0 LIST OF REQUIREMENTS AND TIME FRAMES

This power system is applicable to the following electrical power requirements as marked. The first date listed indicates the earliest time when the system will be available for purchase. Later dates indicate the point in time when significant improvements are expected.

	ELECTRICAL POWER REQUIREMENTS		1977	1985	1990
50 Mw	Continuous	(60 Hz - 3 ø - 13.8 kV)	X	X	X
	1-hour	(60 Hz - 3 ø - 13.8 kV)	X	X	X
10 MW	Continuous	(60 Hz - 3 ø - 4160 V)	X	X	X
	8 - hour	(60 Hz - 3 ø - 4160 V)	X	X	X
	1 - hour	(60 Hz - 3 ø - 4160 V)	X	X	X
750 kw	Continuous	(60 Hz - 3 ø - 4160 V)	X	X	X
250 kw	Continuous	(60 Hz - 3 ø - 480 V)	X	X	X
50 kw	Continuous	(60 Hz - 3 ø - 480 V)	X	X	X
	8 - hour	(60 Hz - 3 ø - 480 V)	X	X	X
	1 - hour	(60 Hz - 3 ø - 480 V)	X	X	X
10 kw	Continuous #1	(DC - 28 V)	X	X	X
	Continuous #2	(60 Hz - 3 ø - 240 V)	X	X	X
	Continuous #3	(60 Hz - 1 ø - 240 V)	X	X	X
	Continuous #4	(60 Hz - 1 ø - 120 V)	X	X	X
	8 - hour #1	(DC - 28 V)	X	X	X
	8 - hour #2	(60 Hz - 3 ø - 240 V)	X	X	X
	1 - hour	(60 Hz - 3 ø - 240 V)	X	X	X

3.0 PARAMETERS

3.1 Acquisition Cost (1977 Dollars)

Requirement	1977, 85, 90*
50 Mw Cont.	6,875,000
50 Mw 1 hr.	6,325,000
10 Mw Cont.	2,450,000
10 Mw 8 hr.	2,118,000
10 Mw 1 hr.	2,118,000
750 kw Cont.	168,800
250 kw Cont.	90,800
50 kw Cont.	20,600
50 kw 8 hr.	18,800
50 kw 1 hr.	18,800
10 kw Cont. # 1, 2, 3, 4	6,800
10 kw 8 hr. # 1, 2	6,200
10 kw 1 hr.	6,200

* Costs will vary ± 15% depending on the manufacturer and accessories, such as the generator voltage. The 50 Mw and 10 Mw size costs include installation and structures. The power system costs are not expected to change significantly in the future.

3.2 Life Cycle Cost (1977 Dollars)

The life cycle cost is defined by the following equation:

$$LCC = AC + FC + OMC$$

where AC = Acquisition Cost (See Section 3.1)

FC = Total Fuel Cost Over System Lifetime (See Section 3.6)

OMC = Operation and Maintenance Cost Over System Lifetime (See Section 3.15)

Requirement	LCC 1977 $			LCC/YR 1977 $		
	1977	1985	1990	1977	1985	1990
50 Mw Cont.	419,875,000	411,846,000	429,176,000	13,996,000	13,728,000	14,306,000
1 hr.	33,838,000	32,669,000	33,358,000	1,128,000	1,089,000	1,112,000
10 Mw Cont.	87,340,000	83,442,000	86,471,000	2,911,000	2,788,000	2,882,000
8 hr.	43,950,000	41,689,000	44,058,000	1,465,000	1,390,000	1,469,000
1 hr.	7,621,000	7,387,000	7,525,000	254,000	246,000	251,000
750 kw Cont.	9,249,000	8,341,000	8,281,000	318,900	287,600	285,500
250 kw Cont.	3,486,000	3,366,000	3,338,000	120,200	116,100	115,100
50 kw Cont.	937,500	803,600	788,400	32,300	27,700	27,200
8 hr.	465,500	412,600	393,500	16,100	14,200	13,600
1 hr.	85,500	76,300	75,200	2,900	2,500	2,500
10 kw Cont. #1, 2, 3, 4	228,500	202,900	195,600	7,900	7,000	6,700
8 hr. #1, 2	117,000	106,000	101,000	4,000	3,700	3,500
1 hr.	25,400	23,900	23,400	850	800	780

3.3 <u>Lifetime (Years)</u>

The useful service life of the power system is indicated in the following table.

Requirement	1977, 85, 90*	Years between Overhaul	No. of Overhauls
50 Mw Cont.	30	16	1
1 hr.	30	34	0
10 Mw Cont.	30	16	1
8 hr.	30	34	0
1 hr.	30	274	0
750 kw Cont.	29	4.9	5
250 kw Cont.	29	4.9	5
50 kw Cont.	29	2.4	11
8 hr.	29	2.1	13
1 hr.	30	16	1
10 kw Cont. #1, 2, 3, 4	29	2.4	11
8 hr. #1, 2	29	2.1	13
1 hr.	30	16	1

*Duration of operational lifetime is not expected to change significantly with future generation engines. Frequent starts will increase required maintenance.

**Lifetime based on USAF definition

3.4 Volume/Size

The volume occupied by the power system is indicated in the following table. The physical proportions can be determined from Section 1.3.

Requirement	1977, 85, 90*	
	Volume ft^3	Volume m^3
50 Mw Cont., 1 hr.	27,500	778.7
10 Mw Cont., 8 hr., 1 hr.	5,500	155.7
750 kw Cont.	375	10.6
250 kw Cont.	150	4.3
50 kw Cont., 8 hr., 1 hr.	47.5	1.4
10 kw Cont. # 1, 2, 3, 4,	12.5	0.4
8 hr. #1, 2, 1 hr.	12.5	0.4

* Power system volume is not expected to change significantly with future generation engines. Sizes can vary ± 30% depending on the manufacturer and accessories. 10 Mw and larger systems are installed out of doors and have their own enclosures.

3.5 Weight

The weight of the power system is indicated in the following tabulation.

	1977, 85, 90			
	System Weight*		Module Weight**	
Requirement	lb	kg	lb	kg
50 Mw Cont., 1 hr.	550,000	250,000	NA	
10 Mw Cont., 8 hr., 1 hr.	125,000	56,700	78,100	35,400
750 kw Cont.	12,800	5,800	NA	
250 kw Cont.	4,500	2,000	NA	
50 kw Cont., 8 hr., 1 hr.	1,000	500	NA	
10 kw Cont. #1, 2, 3, 4,	200	100	NA	
8 hr. #1, 2, 1 hr.	200	100	NA	

* Power System weight is not expected to change significantly with future generation engines. Weights vary ± 50% depending on the manufacturer and accessories. 10 Mw and larger systems are installed out of doors and have their own enclosures.

** System can be designed in two modules to allow transportability. Module weight is for the larger module which houses the turbine-generator.

3.6 Fuel

The cost of No. 2 fuel oil and the quantity consumed by the power system is indicated in the following tabulation.

Requirement	Amount Per Year						Cost Per Year 1977 Dollars			Time Between Deliveries
	1977		1985		1990					
	10^3 gal	10^3 kg	10^3 gal	10^3 kg	10^3 gal	10^3 kg	1977	1985	1990	
50 Mw Cont.	24,300	79,400	20,000	65,400	18,600	60,800	13,261,000	12,993,000	13,571,000	2 weeks
1 hr.	1,500	4,700	1,200	3,900	1,100	3,600	818,600	779,600	802,600	2 weeks
10 Mw Cont.	5,000	16,400	4,000	13,100	3,700	12,100	2,729,000	2,599,000	1,700,000	2 weeks
8 hr.	2,400	7,800	1,900	6,200	1,800	5,800	1,310,000	1,234,000	1,313,000	2 weeks
1 hr.	300	980	240	780	220	720	163,700	155,900	160,500	2 weeks
750 kw Cont.	570	1,900	430	1,400	380	12,600	307,100	275,800	273,800	5 days
250 kw Cont.	210	690	170	540	150	470	113,100	109,000	108,000	5 days
50 kw Cont.	55	180	39	130	34	110	29,600	25,000	24,500	5 days
8 hr.	26	86	19	61	16	53	14,000	12,200	11,500	5 days
1 hr.	3.3	11	2.3	7.6	2.0	6.6	1,800	1,500	1,500	5 days
10 kw Cont. #1, 2, 3, 4	12	39	8.7	29	7.4	24	6,500	5,600	5,300	5 days
10 kw 8 hr. $1, 2	5.7	19	4.2	14	3.5	12	3,100	2,700	2,500	5 days
10 kw 1 hr.	0.71	2.3	0.52	1.7	0.44	1.4	390	340	320	5 days

*Cost per year is calculated by dividing the cost of fuel over the life of the system by the life in years. The system life is given in Section 3.3. The systems begin operation in the respective years indicated.

NOTE: For continuity and the purposes of comparison, the calculations for the advanced generation systems (1985 and 1990) were based on No. 2 fuel oil. The availability of distillate fuels beyond the year 2000 is uncertain, however; and therefore, the longer lived advanced systems may have to operate on coal derived fuels.

Gas turbine power systems can be purchased with the capability of burning natural gas (or other gases with similar heating values) in addition to No. 2 fuel oil at little additional cost. Heavier oils, including crudes and residuals, can also be used but require various amounts of heating and washing at a cost penalty of 10 to 20 percent for the additional equipment.

3.7 Environmental Constraints

The environmental constraints of the power system are indicated in the following tabulation:

X amount of uncontrolled emission

Y Amount of pollution which would be emitted with no controls

Z Degree of difficulty in meeting more strict regulations

Key: blank - none

0 - minor

◐ - moderate

● - major

Emissions	X	Y	Z
Thermal Discharge (a)	●	-	-
Thermal Discharge (b)	-	-	-
Air Pollution			
CO	0	-	0
HC	0	-	0
NO_x	◐	-	●
SO_x	◐	-	◐
Particulates	0	0	0
Noise	●	◐	◐
Solid Waste	-	-	-
Chemical Waste	-	-	-
Radioactive Waste	-	-	-

Notes: (a) system is air or water cooled; heat rejected directly to atmosphere.
(b) system is water cooled; heat rejected to body of water or cooling tower. Water source and/or make-up required.

Gas turbine generator systems are normally supplied with air intake and exhaust silencers which control the principle noise emissions. In addition, complete enclosures are sometimes used to control the noise radiated through the turbine housing. Exhaust particulates are controlled by fuel additives. SO_x emissions are controlled by limiting the sulfur levels in the fuel.

The primary advantage of the gas turbine power system, from the environmental point of view, is that it is directly air cooled and does not require cooling towers.

3.8 Location Constraints

The locational limitations of the power system, and the degree of difficulty in overcoming these limitations are indicated in the following tabulation.

— - no difficulty

O - minor difficulty

◐ - major difficulty

● - overriding limitation

LOCATION RESTRAINT	
Water required for cooling	-
Water required for process	-
Manning required during operation	O
Fuel deliveries required	●
Adequate solar insolation required	-
Adequate wind speed required	-
Isolation from population required	-
Electricity required for charging	-

3.9 Operational Constraints

The tabulated operating characteristics are applicable to the power system as indicated.

— - Characteristic not observed in system operation

O - Characteristic has minor effect on system performance

◐ - Characteristic has moderate effect on system performance

● - Characteristic has major effect on system performance

Operational Restraint	
Efficiency reduction at part load	◐
Part load capability limitation	O
Dependence on solar insolation	-
Dependence on wind consistency	-
Overload capacity limitations	O
Delayed response to rapid load changes	O
Life reduction from frequent rapid load changes	O

3.10 System Efficiency

The power system efficiency is indicated in the following tabulation.

Requirement	Efficiency %*		
	1977	1985	1990
50 Mw Cont., 1 hr.	30.5	37	40
10 Mw Cont., 8 hr., 1 hr.	29.5	37	40
750 kw Cont.	19.5	26	29
250 kw Cont.	17.5	22.5	25.5
50 kw Cont., 8 hr., 1 hr.	13.5	19	22
10 kw Cont. #1, 2, 3, 4	12.5	17	20
8 hr. #1, 2, 1 hr.	12.5	17	20

* Efficiencies indicated for current machines are typical and can vary ± 10% depending on the manufacturer. Efficiencies for future advanced engines are based on the target goals of current research and development programs.

3.11 Type of System

The system type is indicated in the following tabulation.

M - mobile

T - transportable

F - fixed

Time - time for assembly or construction

Requirement	M	T	F	Time
50 Mw Cont., 1 hr.			X	3 mos
10 Mw Cont., 8 hr., 1 hr.		X		3 hrs
750 kw Cont.	X			
250 kw Cont.	X			
50 kw Cont., 8 hr., 1 hr.	X			
10 kw Cont. #1, 2, 3, 4	X			
8 hr. #1, 2, 1 hr.	X			

No change is expected for future generation systems

3.12 Start-up/Shut-down Times

The start-up and shut-down time for the power system is indicated in the following tabulation.

Requirement	Start-up*	Shut-down
50 Mw Cont., 1 hr.	3-20 min.	3-20 min.
10 Mw Cont., 8 hr., 1 hr.	3-5 min.	3-5 min.
750 kw Cont.	10 sec.-1 min.	10 sec.-1 min.
250 kw Cont.	10 sec.-1 min.	10 sec.-1 min.
50 kw Cont., 8 hr., 1 hr.	1 min.	1 min.
10 kw Cont. #1, 2, 3, 4	1 min.	1 min.
8 hr. #1, 2, 1 hr.	1 min.	1 min.

* The start-up times listed are for current generation engines and vary with the manufacturer. It is expected that the average starting time for future generation engines will approach the shortest times for current engines in each size range. Shut-down times were assumed to be the same as start-up since the same inertial and thermal stress factors apply in each case.

3.13 Growth Potential

The power system is not modular in construction. As a result, incremental increases in output cannot be achieved without duplicating the original system

3.14 Reliability

The tabulated conditions exist in the power system to the extent indicated.

— - Condition does not exist in system

O - Condition exists, but its extent is sufficiently minor as to have minimal effect on system performance or reliability

◐ - Condition exists, and its extent is sufficient to have a moderate effect on system performance or reliability

● - Condition exists and is a governing factor in determining system performance and reliability.

Conditions	
Numerous moving parts	0
High temperature operation	●
High stress levels	0
High radiation level	-
Corrosive attack	●
Thermal cycling	0
Non-modular design	●
Solar insolation required	-
Wind required	

3.15 Maintenance and Operation

The annual maintenance and operating costs for the power system are listed in the following tabulation:

Requirement	Operation 1977 $/yr	Maintenance 1977 $/yr*	Personnel Required Continuously
50 Mw Cont.	122,800	383,250	No
50 Mw 1 hr.	7,300	91,250	No
10 Mw Cont.	24,500	76,650	No
10 Mw 8 hr.	11,700	73,000	No
10 Mw 1 hr.	1,460	18,250	No
750 kw Cont.	1,840	15,000	No
250 kw Cont.	1,225	4,980	No
50 kw Cont.	735	3,980	No
50 kw 8 hr.	350	3,860	No
50 kw 1 hr.	45	853	No
10 kw Cont. #1, 2, 3, 4	440	3,260	No
10 kw 8 hr. #1, 2	210	3,130	No
10 kw 1 hr.	25	742	No

*Maintenance costs per kwhr are increased when the unit is started frequently or run at peak ratings. Maintenance includes periodic inspection and repair/replacement of hot gas path parts based on the length of time of operation, operating regime and fuel. Smaller machines are returned to the factory for overhauls and can be exchanged for rebuilt units, minimiziing down time.

3.16 Other Energy Production

Thermal energy can be recovered from the gas turbine exhaust gas which is discharged to the atmosphere. Temperatures are suitable for the production of saturated and superheated steam. Temperatures are lower in the regenerative cycle since heat is removed from the exhaust in the recuperator prior to discharge.

Requirement	1977		1985		1990	
	10^6 Btu/hr	10^3 kw Thermal	10^6 Btu/hr	10^3 kw Thermal	10^6 Btu/hr	10^3 kw Thermal
50 Mw Cont., 1 hr.	233	68.4	174	51.1	154	45.0
10 Mw Cont., 8 hr., 1 hr.	48.9	14.3	34.9	10.2	30.7	9.0
750 kw Cont.	6.34	1.86	4.37	1.28	3.76	1.10
250 kw Cont.	2.41	0.71	1.76	0.52	1.50	0.44
50 kw Cont., 8 hr., 1 hr.	0.66	0.19	0.437	0.13	0.36	0.11
10 kw Cont., #1, 2, 3, 4	0.14	0.04	0.10	0.03	0.082	0.024
8 hr. #1, 2, 1 hr.	0.14	0.04	0.10	0.03	0.082	0.024

The amount of waste heat discharged depends on the thermal efficienty of the power system. The discharge shown for current machines is an average and will vary $\pm$ 15 percent depending on the manufacturer. Future discharges are lower based on the projected higher efficiencies for these machines. (See Section 3.10.)

3.17 Availability of Raw Building Materials

The power system is constructed primarily of iron and nickel based metal alloys; no critically short materials are required.

3.18 Development

Data Not Available

4.0 REFERENCES

1) O'Keefe, W., "In-Plant Electric Generation", Power, pg. 5.1-5.24, April 1975.

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3) "Solar Centaur Gas Turbine Continuous Duty Generator Set", Solar Division of International Harvester Company, T42/372/5M

4) Henry, R.J., "Use of Methanol (a Methyl Fuel) in G.E. Heavy-Duty Gas Turbine", General Electric Co.

5) "Platform Power from TPM", Turbo Power and Marine Systems, Farmington, Connecticut, April 1975.

6) "Sea Level - 60 Hz Performance, MOD POD Power Generation Systems", Curtiss Wright, Power Systems, Wood-Ridge, New Jersey, pg. 1A.

7) Wood, R.G. and Tramuta, S.S., "Reduce Gas-Turbine Fuel Consumption", Power, pg. 63-64, December 1973.

8) "ERDA Backing 2500^{o}F 10-MW Design for 1982", Gas Turbine World, pg. 41, Vol. 7, No. 2, May 1977.

9) "Mobile Power", United Technologies Corp., Power Systems Division, S-7490, February 1977.

10) Private conversation with Solar Inc., June 6, 1977.

11) North American Turbine Corporation (Kongsberg) advertisement, Gas Turbine World, pg. 3, Vol. 7 No. 1, February-March 1977.

12) "New Concept in Gas Turbine Portable Power Plants", Solar Division of International Harvester Company, T-30/470/2.5M.

13) "Utilities Find Industrials and Jets Cost the Same to Maintain", Gas Turbine World, pg. 40-41, March 1975.

14) "Steam-Electric Generating Plant Statistics (Large Plants)", Annual report of Public Service Company of Colorado, Year ended December 31, 1975.

15) Knorr, R.H., "Gas Turbine Maintenance", General Electric Company, 1974.

16) Personal communications with manufacturers.

SECTION IV

GAS TURBINE GENERATOR - REGENERATIVE CYCLE

(CHEMICAL FUEL)

1.0 SYSTEM DESCRIPTION

1.1 System Identification

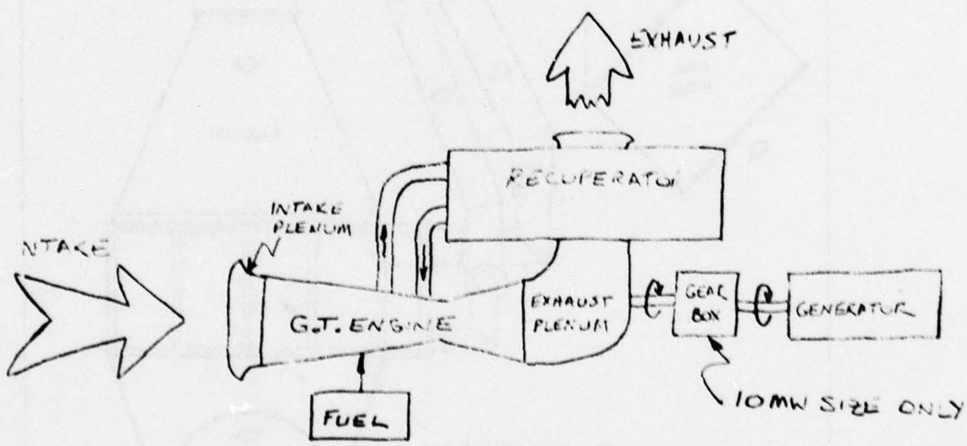
Energy Converter/Cycle - combustion gas turbine/open brayton regenerative cycle

Fuel - No. 2 distillate oil

Working Fluid - air (once through)

Equivalent Alternate Types - natural gas fuel

1.2 System Definition



The major components of the power system consist of the combustion turbine (gas turbine) prime mover, gearbox for the 10 Mw size, generator, control system, fuel system (including two-week capacity storage tank), intake plenum and air filter, exhaust plenum and ducting, and recuperator.

1.3 Physical Description

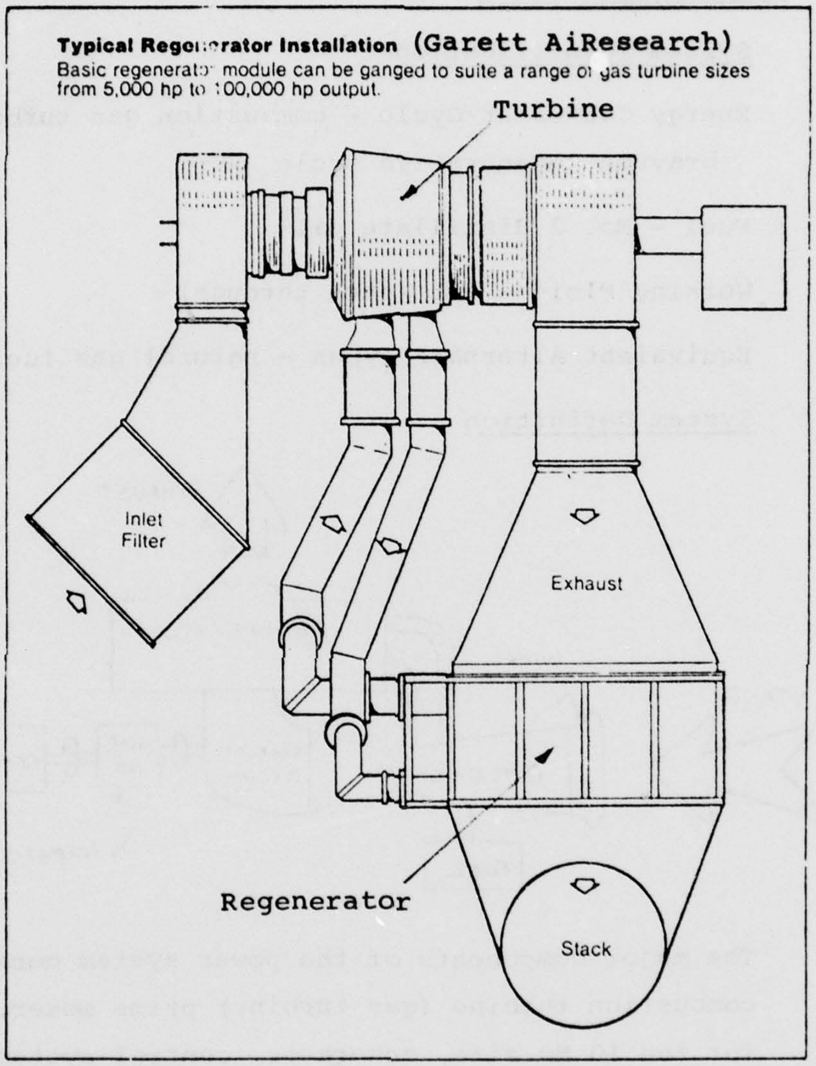


Figure 5. Garrett Regenerative Gas Turbine Generator

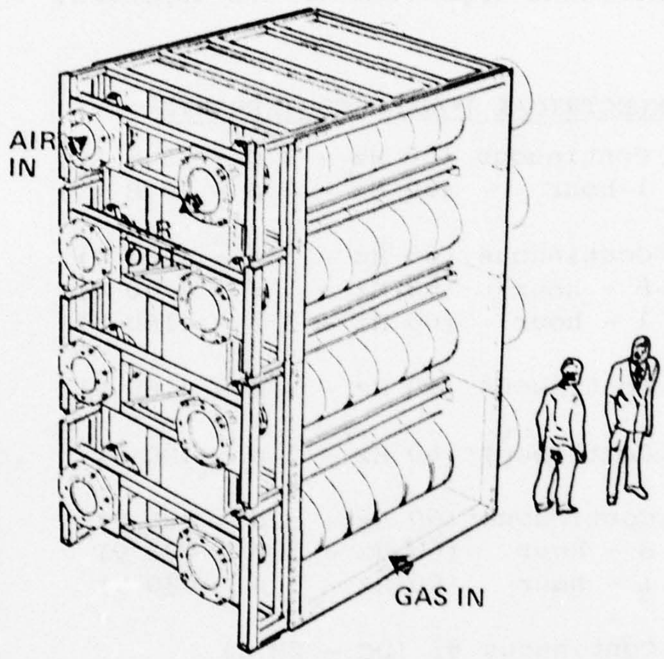


Figure 6. Garrett AiResearch regenerator module suitable for a 22 MW gas turbine

2.0 LIST OF REQUIREMENTS AND TIME FRAMES

This power system is applicable to the following electrical power requirements as marked. The first date listed indicates the earliest time when the system will be available for purchase. Later dates indicate the point in time when significant improvements are expected.

	ELECTRICAL POWER REQUIREMENTS		1977	1985	1990
50 Mw	Continuous	(60 Hz - 3 ø - 13.8 kV)	X	X	X
	1-hour	(60 Hz - 3 ø - 13.8 kV)	X	X	X
10 MW	Continuous	(60 Hz - 3 ø - 4160 V)	X	X	X
	8 - hour	(60 Hz - 3 ø - 4160 V)	X	X	X
	1 - hour	(60 Hz - 3 ø - 4160 V)	X	X	X
750 kw	Continuous	(60 Hz - 3 ø - 4160 V)	N/A*	N/A	N/A
250 kw	Continuous	(60 Hz - 3 ø - 480 V)	N/A	N/A	N/A
50 kw	Continuous	(60 Hz - 3 ø - 480 V)	N/A	N/A	N/A
	8 - hour	(60 Hz - 3 ø - 480 V)	N/A	N/A	N/A
	1 - hour	(60 Hz - 3 ø - 480 V)	N/A	N/A	N/A
10 kw	Continuous #1	(DC - 28 V)	N/A	N/A	N/A
	Continuous #2	(60 Hz - 3 ø - 240 V)	N/A	N/A	N/A
	Continuous #3	(60 Hz - 1 ø - 240 V)	N/A	N/A	N/A
	Continuous #4	(60 Hz - 1 ø - 120 V)	N/A	N/A	N/A
	8 - hour #1	(DC - 28 V)	N/A	N/A	N/A
	8 - hour #2	(60 Hz - 3 ø - 240 V)	N/A	N/A	N/A
	1 - hour	(60 Hz - 3 ø - 240 V)	N/A	N/A	N/A

* It is common practice to use regenerators only on large units due to the high acquisition cost of these items.

3.0 PARAMETERS

3.1 Acquisition Cost (1977 Dollars)

Requirement	1977, 85, 90*
50 Mw Cont.	9,488,000
50 Mw 1 hr.	8,729,000
10 Mw Cont.	3,185,000
10 Mw 8 hr.	3,185,000
10 Mw 1 hr.	3,185,000

*Costs will vary ± 15% depending on the manufacturer and accessories, such as the generator voltage. The 50 Mw and 10 Mw size costs include installation and structures. The power system costs are not expected to change significantly in the future.

3.2 **Life Cycle Cost (1977 Dollars)**

The life cycle cost is defined by the following equation:

LCC = AC + FC + OMC

where AC = Acquisition Cost (See Section 3.1)

FC = Total Fuel Cost Over System Lifetime (See Section 3.6)

OMC = Operation and Maintenance Cost Over System Lifetime (See Section 3.15)

	LCC 10^3 1977 $			LCC/YR 10^3 1977 $		
Requirement	1977	1985	1990	1977	1985	1990
50 Mw Cont.	357,669,000	399,221,000	405,637,000	11,922,000	13,307,000	12,521,000
1 hr.	31,893,000	33,686,000	34,136,000	1,063,000	1,123,000	1,138,000
10 Mw Cont.	75,439,000	80,740,000	83,289,000	2,515,000	2,691,000	2,776,000
8 hr.	38,918,000	41,257,000	41,197,000	1,297,000	1,375,000	1,373,000
1 hr.	7,982,000	8,371,000	8,266,000	266,000	279,000	275,500

3.3 Lifetime (years)

The useful service life of the power system is indicated in the following table.

Requirement	1977, 85, 90*	Years between Overhaul	No. of Overhauls
50 Mw Cont.	30	16	1
1 hr.	30	34	0
10 Mw Cont.	30	16	1
8 hr.	30	34	0
1 hr.	30	274	0

* Duration of operational lifetime is not expected to change significantly with future generation engines. Frequent starts will increase required maintenance.

3.4 Volume/Size

The volume occupied by the power system is indicated in the following table. The physical proportions can be determined from section 1.3.

	1977, 85, 90*	
Requirement	Volume Ft^3	Volume m^3
50 Mw Cont., 1 hr.	43,700	1,240
10 Mw Cont., 8 hr., 1 hr.	8,700	250

* Power system volume is not expected to change significantly with future generation engines. Sizes can vary ± 30% depending on the manufacturer and accessories. 10 Mw and larger systems are installed out of doors and have their own enclosures.

3.5 Weight

The weight of the power system is indicated in the following tabulation.

Requirement	1977, 85, 90 System Weight* 1977 lb	1977 kg	1985 lb	1985 kg
50 Mw Cont., 1 hr	810,000	367,000	698,000	317,000
10 Mw Cont., 8 hr., 1 hr.	184,000	83,000	159,000	72,000

*Gas turbine engine weight is not expected to change significantly with future generation engines. These weights vary ± 50% depending on the manufacturer and accessories.

Reductions in regenerator weight are expected for new generation designs utilizing high temperature, high strength materials.

Ten Mw and larger systems are installed out of doors and have their own enclosures.

3.6 <u>Fuel</u>

The cost of No. 2 fuel oil and the quantity consumed by the power system is indicated in the following tabulation.

Requirement	Amount Per Year 1977 10^3 gal	1977 10^3 kg	1985 10^3 gal	1985 10^3 kg	1990 10^3 gal	1990 10^3 kg	Average Cost Per Year* 1977 Dollars 1977	1985	1990	Time Between Deliveries
50 Mw Cont.	20,200	66,000	19,100	62,400	17,300	56,500	11,023,000	12,408,000	12,622,000	2 weeks
1 hr.	1,200	3,900	1,100	3,600	1,000	3,300	654,800	714,600	729,600	2 weeks
10 Mw Cont.	4,200	13,700	3,800	12,400	3,500	11,400	2,292,000	2,469,000	2,554,000	2 weeks
8 hr.	2,000	6,500	1,800	5,900	1,600	5,200	1,091,000	1,169,000	1,167,000	2 weeks
1 hr.	250	820	230	750	200	650	136,400	149,400	145,900	2 weeks

*Cost per year is calculated by dividing the cost of fuel over the life of the system by the life in years. The system life is given in Section 3.3. The systems being operation in the respective years indicated, and fuel costs are escalated by the method given in Appendix A.

NOTE: For continuity and the purposes of comparison, the calculations for the advanced generation systems (1985 and 1990) were based on No. 2 fuel oil. The availability of distillate fuels beyond the year 2000 is uncertain, however; and therefore, the longer lived advanced systems may have to operate on coal derived fuels.

Gas turbine power systems can be purchased with the capability of burning natural gas (or other gases with similar heating values) in addition to No. 2 fuel oil at little additional cost. Heavier oils, including crudes and residuals, can also be used but require various amounts of heating and washing at a cost penalty of 10 to 20 percent for the additional equipment.

3.7 Environmental Constraints

The environmental constraints of the power system are indicated in the following tabulation:

X amount of uncontrolled emission

Y Amount of pollution which would be emitted with no controls

Z Degree of difficulty in meeting more strict regulations

Key: blank - none

0 - minor

◒ - moderate

● - major

Emissions	X	Y	Z
Thermal Discharge (a)	●	-	-
Thermal Discharge (b)	-	-	-
Air Pollution			
CO	0	-	0
HC	0	-	0
NO_x	◒	-	●
SO_x	◒	-	◒
Particulates	◒	0	◒
Noise	●	◒	◒
Solid Waste	-	-	-
Chemical Waste	-	-	-
Radioactive Waste	-	-	-

Notes: (a) system is air or water cooled; heat rejected directly to atmosphere.

(b) system is water cooled; heat rejected to body of water or cooling tower. Water source and/or make-up required.

Gas turbine generator systems are normally supplied with air intake and exhaust silencers which control the principle noise emissions. In addition, complete enclosures are sometimes used to control the noise radiated through the turbine housing. Exhaust particulates are controlled by fuel additives. SO_x emissions are controlled by limiting the sulfur levels in the fuel.

The primary advantage of the gas turbine power system, from the environmental point of view, is that it is directly air cooled and does not require cooling towers.

3.8 Location Constraints

The locational limitations of the power system, and the degree of difficulty in overcoming these limitations are indicated in the following tabulation.

— - no difficulty

O - minor difficulty

◐ - major difficulty

● - overriding limitation

LOCATION RESTRAINT	
Water required for cooling	-
Water required for process	-
Manning required during operation	O
Fuel deliveries required	●
Adequate solar insolation required	-
Adequate wind speed required	-
Isolation from population required	-
Electricity required for charging	-

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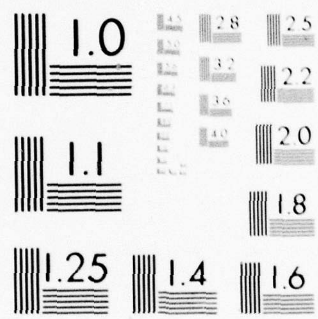

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3.9 Operational Constraints

The tabulated operating characteristics are applicable to the power system as indicated.

– Characteristic not observed in system operation

O – Characteristic has minor effect on system performance

◓ – Characteristic has moderate effect on system performance

● – Characteristic has major effect on system performance

Operational Restraint	
Efficiency reduction at part load	◓
Part load capability limitation	O
Dependence on solar insolation	-
Dependence on wind consistency	-
Overload capacity limitations	O
Delayed response to rapid load changes	◓
Life reduction from frequent rapid load changes	◓

3.10 System Efficiency

The power system efficiency is indicated in the following tabulation.

Requirement	Efficiency %*		
	1977	1985	1990
50 Mw Cont., 1 hr.	37	39	43
10 Mw Cont., 8 hr., 1 hr.	35	39	43

* Efficiencies indicated for current machines are typical and can vary ± 10% depending on the manufacturer. Efficiencies for future advanced engines are based on the target goals of current research and development programs.

3.11 Type of System

The system type is indicated in the following tabulation.

M - mobile

T - transportable

F - fixed

Time - time for assembly or construction

Requirement	M	T	F	Time
50 Mw Cont., 1 hr.			X	3 mos.
10 Mw Cont., 8 hr., 1 hr.			X	3 mos.

No change is expected for future generation systems

3.12 Start-up and Shut-down Times

The start-up and shut-down time for the power system is indicated in the following tabulation.

	Start-up*			Shutdown	
	1977				
Requirement	Cold Regenerator	Hot Regenerator	1985	1977	1985
50 Mw Cont., 1 hr.	1½ hr.	1 hr.	20 min.	1 hr.	20 min.
10 Mw Cont., 8 hr., 1 hr.	1½ hr.	1 hr.	5 min.	1 hr.	5 min.

* The start-up times listed are for current generation engines and vary with the manufacturer. It is expected that the next generation of regenerators will be designed for thermal cycling use and will therefore allow the gas turbine to start or stop at its normal rate without excessive stress levels resulting from thermal gradients in the regenerator. Shut-down times are assumed to be the same as start-up since the same inertial and thermal stress factors apply in each case.

3.13 Growth Potential

The power system is not modular in construction. As a result, incremental increases in output cannot be achieved without duplicating the original system.

3.14 Reliability

The tabulated conditions exist in the power system to the extent indicated.

— - Condition does not exist in system

O - Condition exists, but its extent is sufficiently minor as to have minimal effect on system performance or reliability

◐ - Condition exists, and its extent is sufficient to have a moderate effect on system performance or reliability

● - Condition exists and is a governing factor in determining system performance and reliability.

Conditions	
Numerous moving parts	O
High temperature operation	●
High stress levels	O
High radiation level	-
Corrosive attack	●
Thermal cycling	◐
Non-modular design	●
Solar insolation required	-
Wind required	-

3.15 Maintenance and Operation

The annual maintenance and operating costs for the power system are listed in the following tabulation.

Requirement	Operation 1977 $/yr	Maintenance 1977 $/yr*	Personnel Required Continuously
50 Mw Cont.	122,800	460,000	No
50 Mw 1 hr.	7,300	110,000	No
10 Mw Cont.	24,500	92,000	No
10 Mw 8 hr.	11,700	88,000	No
10 Mw 1 hr.	1,460	22,000	No

* Includes routine maintenance and overhaul costs. Maintenance costs per kwhr are increased when the unit is started frequently or run at peak ratings. Maintenance includes periodic inspection and repair/replacement of hot gas path parts based on the length of time of operation, operating regime and fuel.

3.16 Other Energy Production

Thermal energy can be recovered from the gas turbine exhaust gas which is discharged to the atmosphere. Temperatures are suitable for the production of saturated and superheated steam. Temperatures are higher in the simple cycle since no heat is removed from the exhaust prior to discharge.

Requirement	1977 10^6 Btu/hr	1977 10^3 kw Thermal	1985 10^6 Btu/hr	1985 10^3 kw Thermal	1990 10^6 Btu/hr	1990 10^3 kw Thermal
50 Mw Cont.,	174	51.1	160	46.9	136	39.8
1 hr.	174	51.1	160	46.9	136	39.8
10 Mw Cont.,	38.0	11.1	32.0	9.39	27.2	7.95
8 hr., 1 hr.	38.0	11.1	32.0	9.39	27.2	7.95

The amount of waste heat discharged depends on the thermal efficiency of the power system. The discharge shown for current machines is an average and will vary ± 15 percent depending on the manufacturer. Future discharges are lower based on the projected higher efficiencies for these machines. (See Section 3.10.)

3.17 Availability of Raw Building Materials

The power system is constructed primarily of iron and nickel based alloys; no critically short materials are required.

3.18 Development

Data Not Available

4.0 REFERENCES

1) Stambler, I., "Working on 5000-Cycle Trouble-Free Regenerator", Gas Turbine World, pg. 30-33, July 1976.

2) McDonald, C.F., "Recuperator Development Trends for Future High Temperature Gas Turbines", ASME 75-GT-50.

3) "The Regenerative-Cycle Gas Turbine", General Electric Company, Schenectady, New York, 1974.

4) Personal communications with manufacturers.

SECTION V

DIESEL GENERATOR (CHEMICAL FUEL)

1.0 SYSTEM DESCRIPTION

1.1 System Identification

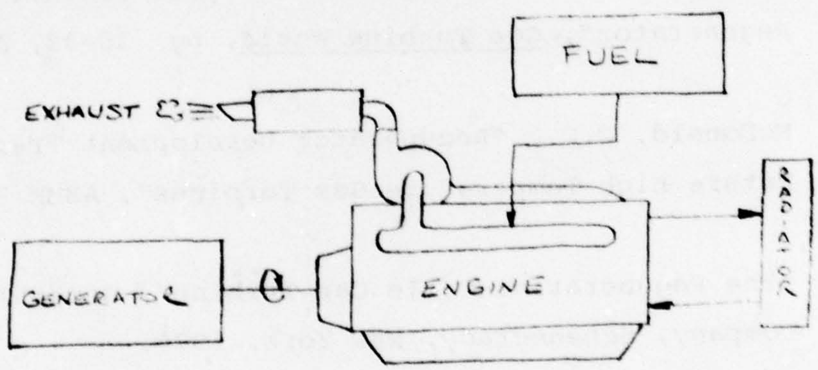
Energy Converter/Cycle - diesel engine generator set/ diesel cycle

Fuel - No. 2 distillate oil

Working Fluid - air (once through)

Equivalent Alternate Types - none

1.2 System Definition



The major components of the power system consist of the diesel engine prime mover, the generator, control system, fuel system (including two-week capacity storage tank for requirements of 10 Mw and above and five-day capacity for requirements below 10 Mw), exhaust system (including muffler), and cooling system (air cooled: 10 kw system, liquid cooled with radiator: 50 kw to 10 Mw system).

1.3 Physical Description

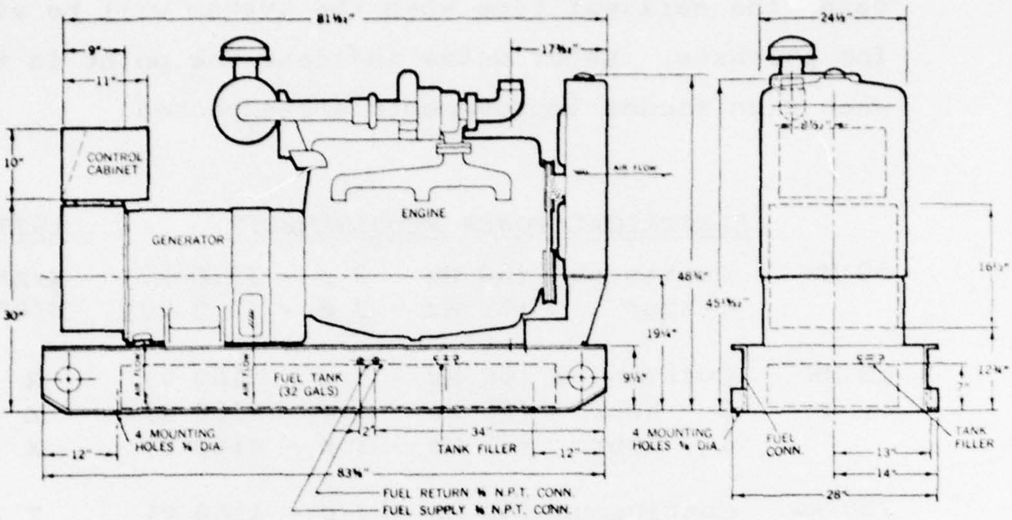


Figure 7. Allis-Chalmers 60 KW Diesel Engine-Generator

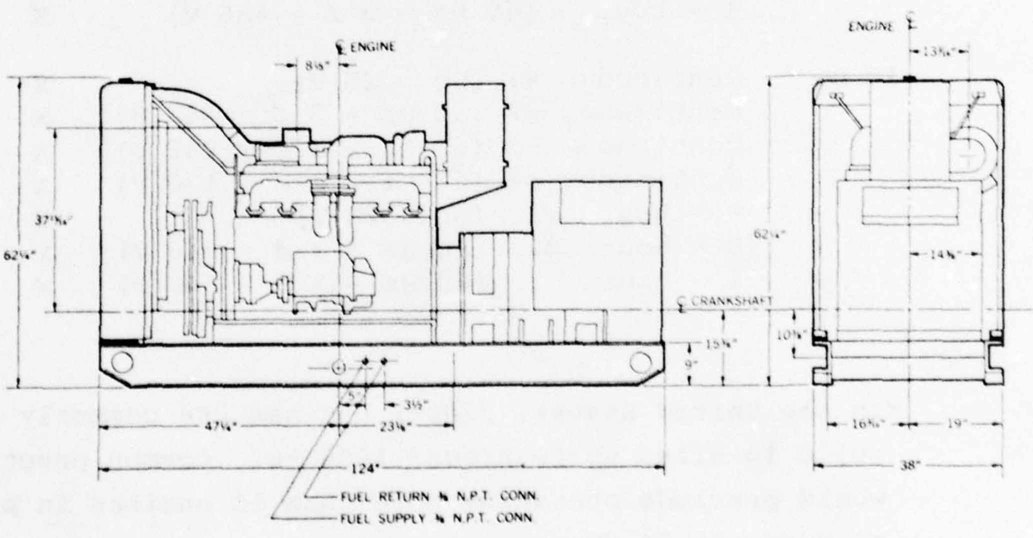


Figure 8. Allis-Chalmers 250 KW Diesel Engine-Generator

2.0 LIST OF REQUIREMENTS AND TIME FRAMES

This power system is applicable to the following electrical power requirements as marked. The first date listed indicates the earliest time when the system will be available for purchase. Later dates indicate the point in time when significant improvements are expected.

	ELECTRICAL POWER REQUIREMENTS		1977
50 Mw	Continuous	(60 Hz - 3 ø - 13.8 kV)	N/A*
	1-hour	(60 Hz - 3 ø - 13.8 kV)	N/A*
10 MW	Continuous	(60 Hz - 3 ø - 4160 V)	X
	8 - hour	(60 Hz - 3 ø - 4160 V)	X
	1 - hour	(60 Hz - 3 ø - 4160 V)	X
750 kw	Continuous	(60 Hz - 3 ø - 4160 V)	X
250 kw	Continuous	(60 Hz - 3 ø - 480 V)	X
50 kw	Continuous	(60 Hz - 3 ø - 480 V)	X
	8 - hour	(60 Hz - 3 ø - 480 V)	X
	1 - hour	(60 Hz - 3 ø - 480 V)	X
10 kw	Continuous #1	(DC - 28 V)	X
	Continuous #2	(60 Hz - 3 ø - 240 V)	X
	Continuous #3	(60 Hz - 1 ø - 240 V)	X
	Continuous #4	(60 Hz - 1 ø - 120 V)	X
	8 - hour #1	(DC - 28 V)	X
	8 - hour #2	(60 Hz - 3 ø - 240 V)	X
	1 - hour	(60 Hz - 3 ø - 240 V)	X

*In the United States, diesel engines are commonly built in sizes up to around 1000 kw. Common practice would preclude operating more than 10 engines in parallel to meet the 50 MW requirements.

3.0 PARAMETERS

3.1 Acquisition Cost (1977 Dollars)

Requirement	1977*
10 Mw Cont.	1,300,000
8 hr.	1,200,000
1 hr.	1,200,000
750 kw Cont.	97,500
250 kw Cont.	35,300
50 kw Cont.	12,500
8 hr.	10,000
1 hr.	10,000
10 kw Cont. #1, 2, 3, 4	3,700
8 hr. #1, 2	3,300
1 hr.	3,300

*Costs will vary ± 15% depending on the manufacturer and accessories, such as the generator voltage. The power system costs are not expected to change significantly in the future.

3.2 Life Cycle Cost (1977 Dollars)

The life cycle cost is defined by the following equation:

LCC = AC + FC + OMC

where AC = Acquisition Cost (See Section 3.1)

FC = Total Fuel Cost Over System Lifetime (See Section 3.6)

OMC = Operation and Maintenance Cost Over System Lifetime (See Section 3.15)

Requirement	LCC 10^3 1977\$	LCC/YR 10^3 1977\$
	1977	1977
10 Mw Cont.	49,953,000	2,449,000
8 hr.	33,036,000	1,285,000
1 hr.	6,730,000	196,200
750 kw Cont.	3,929,000	192,600
250 kw Cont.	1,320,000	64,700
50 kw Cont.	198,200	16,100
8 hr.	115,800	8,900
1 hr.	48,600	1,500
10 kw Cont. #1, 2, 3, 4	45,000	5,500
8 hr. #1, 2	30,100	3,500
1 hr.	17,700	540

3.3 Lifetime (years)

Requirement	1977*	Years between Overhauls	No. of Overhauls
10 Mw Cont.	20	4.1	4
8 hr.	26	5.1	4
1 hr.	34	34.3	0
750 kw Cont.	20	4.1	4
250 kw Cont.	20	4.1	4
50 kw Cont.	12	2.5	4
8 hr.	13	2.6	4
1 hr.	33	16.4	1
10 kw Cont. #1, 2, 3, 4	8	1.6	4
8 hr. #1, 2	9	1.7	4
1 hr.	33	11.0	2

*Duration of operational lifetime is not expected to change significantly in the future. Frequent starts will increase required maintenance.

3.4 Volume/Size

The volume occupied by the power system is indicated in the following table. The physical proportions can be determined from Section 1.3.

Requirement	Volume* ft^3	Volume* m^3
10 Mw Cont., 8 hr., 1 hr.	10,070**	285**
750 kw Cont.	600	17
250 kw Cont.	200	5.7
50 kw Cont., 8 hr., 1 hr.	79	2.2
10 kw Cont. # 1, 2, 3, 4,	24	0.67
8 hr. #1, 2, 1 hr.	24	0.67

* Power system volume is not expected to change significantly with future generation engines. Sizes can vary $\pm$ 10% depending on the manufacturer and accessories.

** 10 Mw requirement consists of ten 1000 kw units operating in parallel.

3.5 Weight

The weight of the power system is indicated in the following tabulation.

Requirement	System Weight*		Module Weight	
	lb	kg	lb	kg
10 Mw Cont., 8 hr., 1 hr.	330,000**	150,000**	33,000	934
750 kw Cont.	18,750	8,500	NA	
250 kw Cont.	7,100	3,200	NA	
50 kw Cont., 8 hr., 1 hr.	2,430	1,100	NA	
10 kw Cont. #1, 2, 3, 4,	620	280	NA	
8 hr. #1, 2, 1 hr.	620	280	NA	

* Power System weight is not expected to change significantly with future generation engines. Weights vary ± 10% depending on the manufacturer and accessories.

** Ten Mw requirement consists of ten 10,000 kw units operating in parallel.

3.6 **Fuel**

The cost of No. 2 fuel oil and the quantity consumed by the power system is indicated in the following tabulation.

Requirement	Amount Per Year		Average Cost Per Year* 10^3 Dollars (1977)	Time Between Deliveries
	10^3gal	10^3kg		
10 Mw Cont.	4,476	14,631	2,183	2 weeks
10 Mw 8 hr.	2,132	6,967	1,110	2 weeks
10 Mw 1 hr.	266	871	154	2 weeks
750 kw Cont.	354	1,157	173	5 days
250 kw Cont.	115	376	56	5 days
50 kw Cont.	24.5	80.2	10.8	5 days
50 kw 8 hr.	11.7	38.2	5.20	5 days
50 kw 1 hr.	1.46	4.77	0.83	5 days
10 kw Cont., #1, 2, 3, 4	5.40	17.6	2.30	5 days
10 kw 8 hr #1, 2	2.57	8.40	1.10	5 days
10 kw 1 hr.	0.32	1.05	0.18	5 days

* Cost per year is calculated by dividing the cost of fuel over the life of the system by the life in years. The system life is given in Section 3.3. The systems begin operation in the respective years indicated, and fuel costs are escalated by the method given in Appendix A .

3.7 Environmental Constraints

The environmental constraints of the power system are indicated in the following tabulation:

X amount of uncontrolled emission

Y Amount of pollution which would be emitted with no controls

Z Degree of difficulty in meeting more strict regulations

Key: blank - none

0 - minor

◐ - moderate

● - major

Emissions	X	Y	Z
Thermal Discharge (a)	●	-	-
Thermal Discharge (b)	-	-	-
Air Pollution			
CO	0	-	0
HC	0	-	0
NO_x	◐	-	◐
SO_x	◐	-	◐
Particulates	0	0	◐
Noise	●	◐	◐
Solid Waste	-	-	-
Chemical Waste	-	-	-
Radioactive Waste	-	-	-

Notes: (a) system is air or water cooled; heat rejected directly to atmosphere.
(b) system is water cooled; heat rejected to body of water or cooling tower. Water source and/or make-up required.

Diesel engine generator systems are normally supplied with exhaust silencers (mufflers) to control the principle noise emissions. Exhaust particulates are controlled by fuel additives and metering adjustments. SO_x emissions are controlled by limiting the sulfur levels in the fuel. In the power size ranges considered here, air cooling or closed cooling systems are used, requiring only makeup water, not a large supply for once-through cooling or a cooling tower.

3.8 Location Constraints

The locational limitations of the power system, and the degree of difficulty in overcoming these limitations are indicated in the following tabulation.

— - no difficulty
O - minor difficulty
◐ - major difficulty
● - overriding limitation

LOCATION RESTRAINT	
Water required for cooling	-
Water required for process	-
Manning required during operation	-
Fuel deliveries required	●
Adequate solar insolation required	-
Adequate wind speed required	-
Isolation from population required	-
Electricity required for charging	-

3.9 Operational Constraints

The tabulated operating characteristics are applicable to the power system as indicated.

— - Characteristic not observed in system operation

O - Characteristic has minor effect on system performance

◐ - Characteristic has moderate effect on system performance

● - Characteristic has major effect on system performance

Operational Restraint	
Efficiency reduction at part load	O
Part load capability limitation	O
Dependence on solar insolation	-
Dependence on wind consistency	-
Overload capacity limitations	O
Delayed response to rapid load changes	O
Life reduction from frequent rapid load changes	O

3.10 System Efficiency

The power system efficiency is indicated in the following tabulation.

Requirement	Efficiency %*
10 Mw Cont., 8 hr., 1 hr.	32.3**
750 kw Cont.	32.3
250 kw Cont.	30.6
50 kw Cont., 8 hr., 1 hr.	28.1
10 kw Cont. #1, 2, 3, 4	27.5
8 hr. #1, 2, 1 hr.	27.5

* Efficiencies listed are typical for current machines and can vary ± 10% depending on the manufacturer. Efficiencies are not expected to change in the future.

** 10 Mw requirement consists of ten 1000 kw units operating in parallel.

3.11 Type of System

The system type is indicated in the following tabulation.

M - mobile

T - transportable

F - fixed

Time - time for assembly or construction

Requirement	M	T	F	Time
10 Mw Cont., 8 hr., 1 hr.		X		8 hrs
750 kw Cont.	X			
250 kw Cont.	X			
50 kw Cont., 8 hr., 1 hr.	X			
10 kw Cont. #1, 2, 3, 4	X			
8 hr. #1, 2, 1 hr.	X			

No change is expected for future generation systems

3.12 Start-up/Shut-down Time

The start-up and shut-down time for the power system is indicated in the following tabulation.

Requirement	Start-up*	Shut-down
10 Mw Cont., 8 hr., 1 hr.	10 sec.	10 sec.
750 kw Cont.	10 sec.	10 sec.
250 kw Cont.	10 sec.	10 sec.
50 kw Cont., 8 hr., 1 hr.	10 sec.	10 sec.
10 kw Cont. #1, 2, 3, 4	10 sec.	10 sec.
8 hr. #1, 2, 1 hr.		

* The start-up times listed are typical for current generation engines and vary with the manufacturer. No significant changes are expected in the future. Shut-down times can be assumed to be the same as start-up since the same inertial and thermal stress factors apply in each case.

3.13 Growth Potential

The power system is not modular in construction (except for the 10 MW case which utilizes multiple units operating in parallel). As a result, incremental increases in output cannot be achieved without duplicating the original system (except for the 10 MW case).

3.14 Reliability

The tabulated conditions exist in the power system to the extent indicated.

— - Condition does not exist in system

O - Condition exists, but its extent is sufficiently minor as to have minimal effect on system performance or reliability

◐ - Condition exists, and its extent is sufficient to have a moderate effect on system performance or reliability

● - Condition exists and is a governing factor in determining system performance and reliability.

Conditions	
Numerous moving parts	●
High temperature operation	O
High stress levels	O
High radiation level	-
Corrosive attack	O
Thermal cycling	O
Non-modular design	●
Solar insolation required	-
Wind required	-

3.15 <u>Maintenance and Operation</u>

The annual maintenance and operating costs for the power system are listed in the following tabulation.

Requirement	Operation 1977 $/Yr	Maintenance 1977 $/yr*	Personnel Required Continuously
10 Mw Cont.	24,500	179,000	No
8 hr.	11,700	73,800	No
1 hr.	1,460	5,300	No
750 kw Cont.	1,840	13,400	No
250 kw Cont.	1,225	5,700	No
50 kw Cont.	735	3,600	No
8 hr.	350	2,600	No
1 hr.	45	295	No
10 kw Cont. #1, 2, 3, 4	440	2,400	No
8 hr. #1, 2	210	1,800	No
1 hr.	25	230	No

*Includes routine maintenance and overhaul costs. Maintenance costs per kwhr are increased when the unit is started frequently or run at peak ratings.

3.16 Other Energy Production

Thermal energy can be recovered from the engine jacket cooling water, and from the engine exhaust. The temperature of the engine jacket is suitable for the production of hot water, while the exhaust temperature is suitable for the production of saturated or super heated steam.

Requirement	10^6 Btu/hr	10^3 kw Thermal
10 Mw Cont., 8 hr., 1 hr.	42.9	12.6
750 kw Cont.	3.22	0.94
250 kw Cont.	1.16	0.34
50 kw Cont., 8 hr., 1 hr.	0.26	0.077
10 kw Cont. #1, 2, 3, 4,	0.054	0.016
8 hr. #1, 2, 1 hr.	0.054	0.016

The amount of waste heat discharged depends on the thermal efficiency of the power system which is not expected to change significantly in the future. The discharge shown is an average for current machines and will vary $\pm$ 15 percent depending on the manufacturer.

3.17 Availability of Raw Building Materials

The power system is constructed primarily of iron and nickel based metal alloys; no critically short materials are required.

3.18 Development

The power system is available now - no development is necessary.

4.0 REFERENCES

1) O'Keefe, W., "In-Plant Electric Generation", Power, pg. 5.1-5.24, April 1975.

2) "Caterpillar G398 Natural Gas Electric Sets", Caterpillar Tractor Company, LEO 21101-02 (3-70)

3) "Answers to Questions About Diesels", Cummins Engine Company, Inc., Columbus Indiana, Bulletin 3382002 Rev. 5/74.

4) Detroit Diesel Allison advertisement, Gas Turbine World, pg. 17, Vol. 7 No. 2, May 1977.

5) Personal communications with manufacturers.

SECTION VI

SPARK IGNITION ENGINE GENERATOR (CHEMICAL FUEL)

1.0 SYSTEM DESCRIPTION

1.1 System Identification

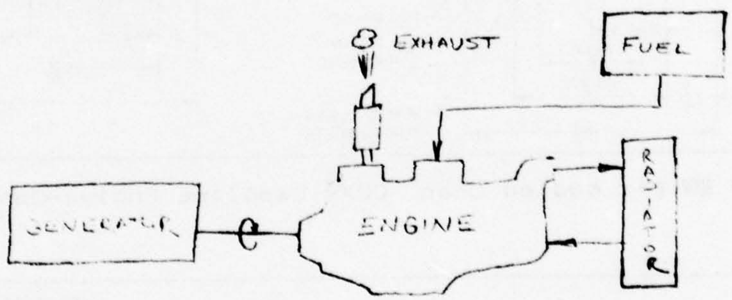
Energy converter/Cycle - diesel engine generator set/otto cycle

Fuel - gasoline

Working Fluid - air (once through)

Equivalent Alternate Types - none

1.2 System Definition



The major components of the power system consist of the gasoline engine prime mover, the generator, control system, fuel system (including five-day storage tank), exhaust system (including muffler), and cooling system. (Engines are liquid cooled, requiring a radiator except for one portable 10 kw unit which is air cooled).

1.3 **Physical Description**

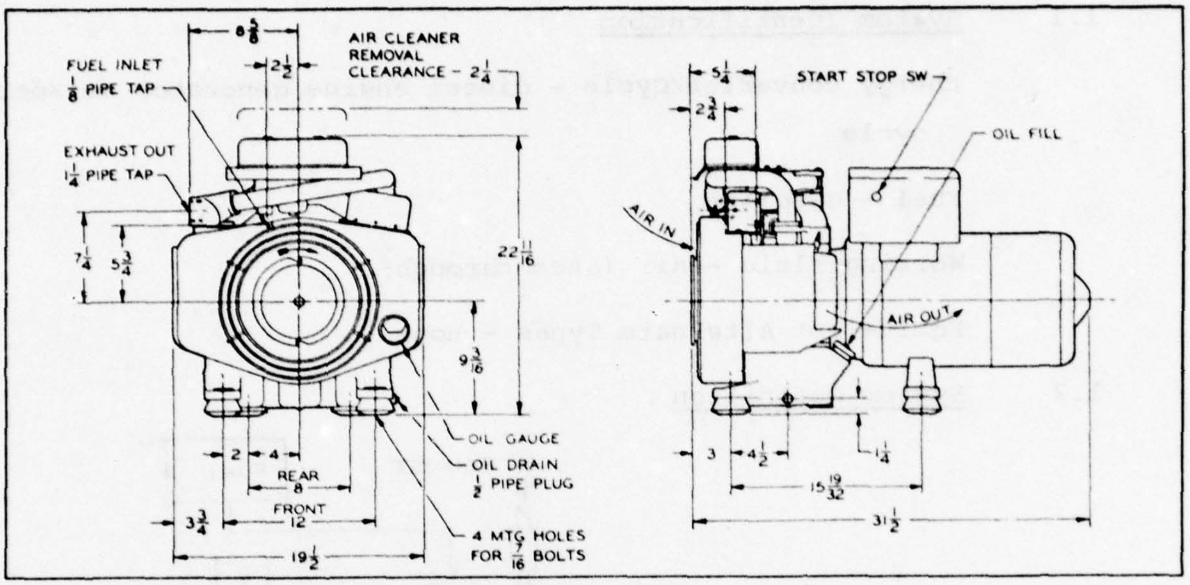


Figure 9. 10 KW air cooled Onan CCKB Gasoline Engine-Generator

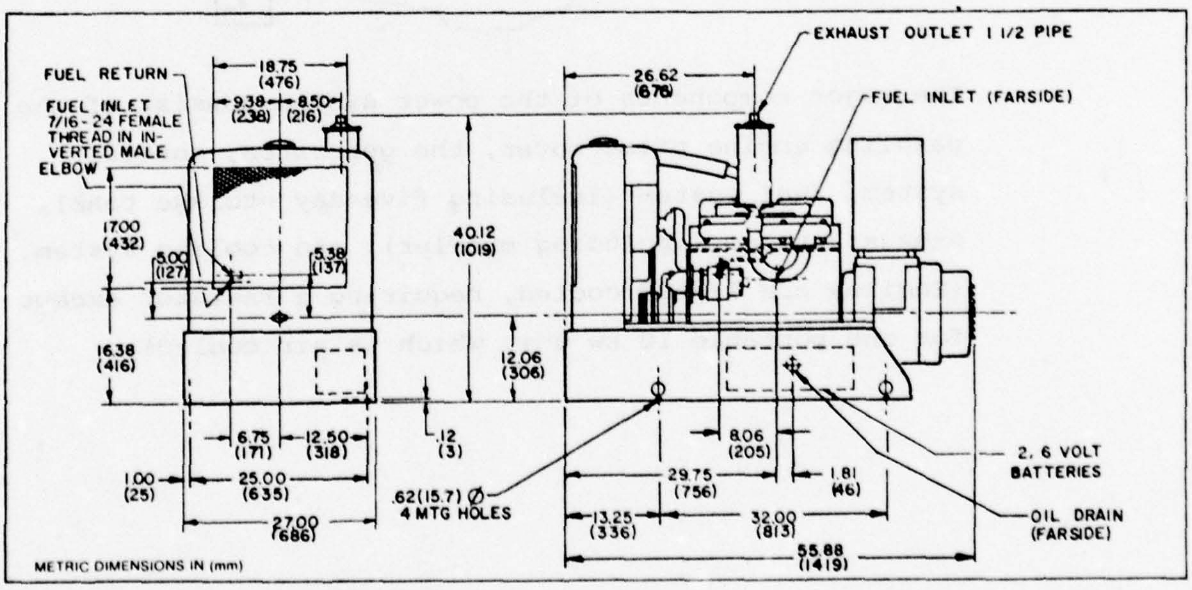


Figure 10. 12.5 KW water cooled Onan RJC Gasoline Engine-Generator

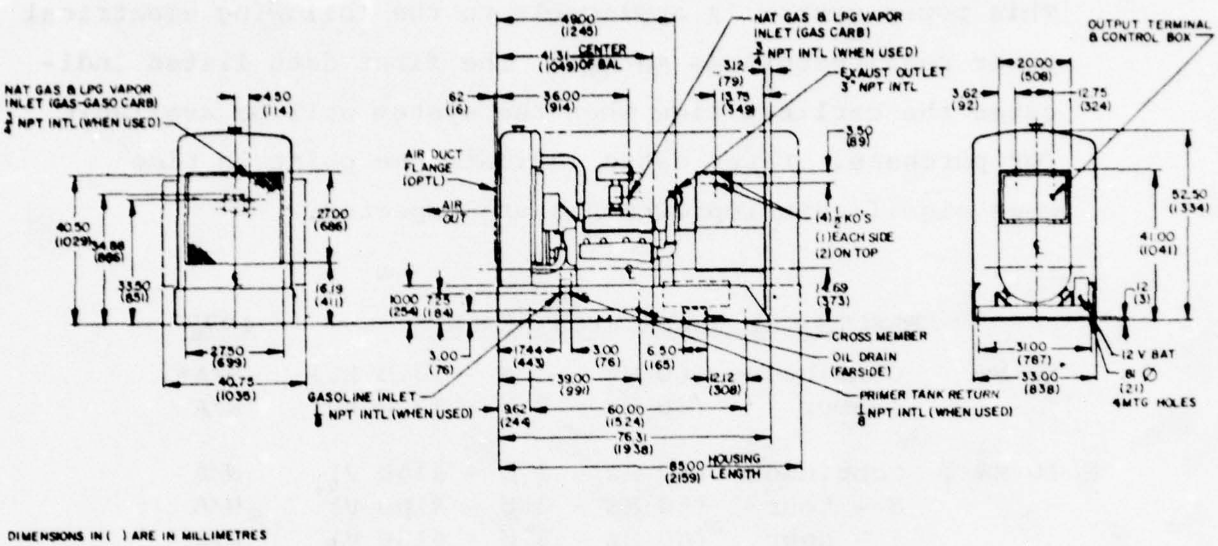


Figure 11. 55 KW water cooled Onan Gasoline Engine-Generator

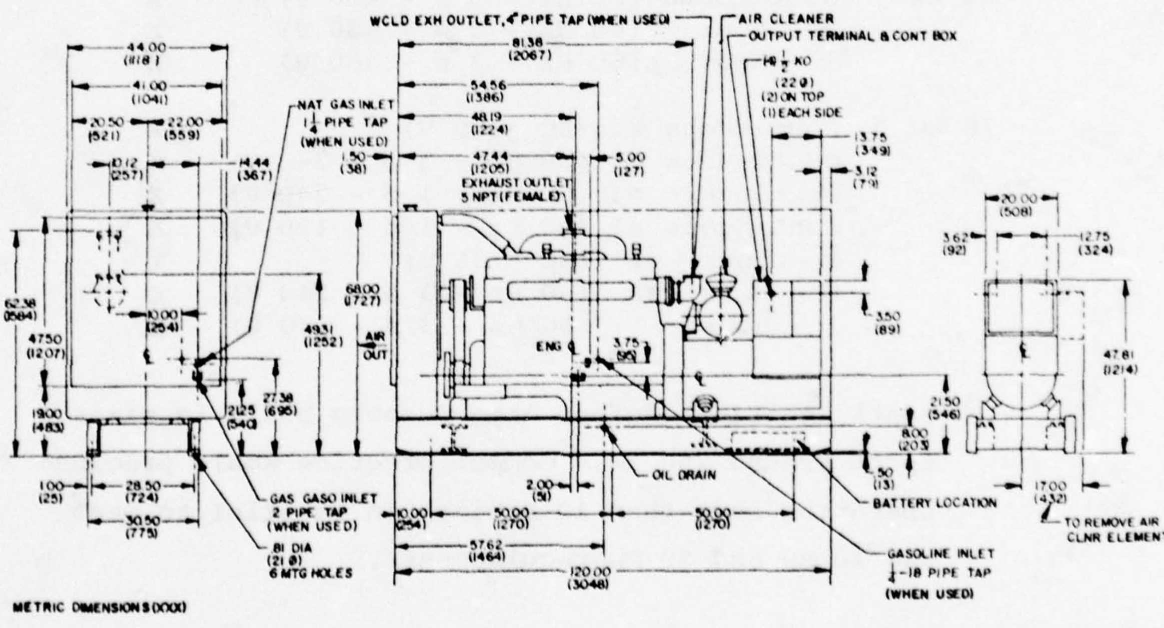


Figure 12. 170 KW water cooled Onan Gasoline Engine-Generator

2.0 LIST OF REQUIREMENTS AND TIME FRAMES

This power system is applicable to the following electrical power requirements as marked. The first date listed indicates the earliest time when the system will be available for purchase. Later dates indicate the point in time when significant improvements are expected.

	ELECTRICAL POWER REQUIREMENTS		1977
50 Mw	Continuous	(60 Hz - 3 ø - 13.8 kV)	N/A*
	1-hour	(60 Hz - 3 ø - 13.8 kV)	N/A
10 MW	Continuous	(60 Hz - 3 ø - 4160 V)	N/A
	8 - hour	(60 Hz - 3 ø - 4160 V)	N/A
	1 - hour	(60 Hz - 3 ø - 4160 V)	N/A
750 kw	Continuous	(60 Hz - 3 ø - 4160 V)	X
250 kw	Continuous	(60 Hz - 3 ø - 480 V)	X
50 kw	Continuous	(60 Hz - 3 ø - 480 V)	X
	8 - hour	(60 Hz - 3 ø - 480 V)	X
	1 - hour	(60 Hz - 3 ø - 480 V)	X
10 kw	Continuous #1	(DC - 28 V)	X
	Continuous #2	(60 Hz - 3 ø - 240 V)	X
	Continuous #3	(60 Hz - 1 ø - 240 V)	X
	Continuous #4	(60 Hz - 1 ø - 120 V)	X
	8 - hour #1	(DC - 28 V)	X
	8 - hour #2	(60 Hz - 3 ø - 240 V)	X
	1 - hour	(60 Hz - 3 ø - 240 V)	X

* Spark ignition engines are commonly built in sizes up to around 250 kw. Common practice would preclude operating more than 10 engines in parallel to meet the 10 Mw and 50 Mw requirements.

3.0 PARAMETERS

3.1 Acquisition Cost (1977 Dollars)

Requirement	1977
750 kw Cont.	119,600*
250 kw Cont.	39,900
50 kw Cont.	8,000
50 kw 8 hr.	7,300
50 kw 1 hr.	7,300
10 kw Cont. #1, 2, 3, 4	3,000
10 kw 8 hr. #1, 2	2,700
10 kw 1 hr.	2,700
10 kw 1 hr.	1,900**

* Costs will vary ± 15% depending on the manufacturer and accessories, such as the generator voltage. The power system costs are not expected to change significantly in the future.

** Portable air cooled unit not intended for continuous operation. Other units are water cooled.

3.2 Life Cycle Cost (1977 Dollars)

The life cycle cost is defined by the following equation:

LCC = AC + FC + OMC

where: AC = Acquisition Cost (See Section 3.1)

FC = Total Fuel Cost Over System Lifetime (See Section 3.6)

OMC = Operation and Maintenance Cost Over System Lifetime (See Section 3.15).

Requirement	LCC 10^3 1977$	LCC/YR 10^3 1977$
750 kw Cont.	3,618	362
250 kw Cont.	1,232	123
50 kw Cont.	177	29.5
50 kw 8 hr.	96.9	16.1
50 kw 1 hr.	86.8	2.60
10 kw Cont. #1, 2, 3, 4	37.1	9.30
10 kw 8 hr. #1, 2	23.1	5.80
10 kw 1 hr.	23.5	0.84
10 kw 1 hr.	4.14**	1.30**

** Portable air cooled unit not intended for continuous operation. Other units are water cooled.

3.3 Lifetime (years)

The useful service life of the power system is indicated in the following table.

Requirement	1977*	Years between Overhaul	No. of Overhauls
750 kw Cont.	10	2.0	4
250 kw Cont.	10	2.0	4
50 kw Cont.	6	1.2	4
8 hr.	6	1.3	4
1 hr.	33	8.2	3
10 kw Cont. #1, 2, 3, 4	4	0.8	4
8 hr. #1, 2	4	0.9	4
1 hr.	28	5.5	4
1 hr.	3.2**	-	-

* Duration of operational lifetime is not expected to change significantly in the future. Frequent starts will increase required maintenance.

** Portable air cooled unit not intended for continuous operation. Other units are water cooled.

3.4 Volume/Size

The volume occupied by the power system is indicated in the following table. The physical proportions can be determined from section 1.3.

Requirement	Volume* ft^3	Volume* m^3
750 kw Cont.	1565**	44.3**
250 kw Cont.	313	8.8
50 kw Cont., 8 hr., 1 hr.	74	2.1
10 kw Cont. #1, 2, 3, 4,	28	0.79
8 hr. #1, 2, 1 hr.	28	0.79
10 kw, 1 hr.	8.1***	0.23***

* Power system volume is not expected to change significantly with future generation engines. Sizes can vary ± 10% depending on the manufacturer and accessories.

** 750 kw requirement consists of three 250 kw units operating in parallel

*** Portable air cooled unit not intended for continuous applications. Other units water cooled.

3.5 Weight

The weight of the power system is indicated in the following tabulation.

Requirement	System Weight*		Module Weight	
	lb	kg	lb	kg
750 kw Cont.	28,500**	12,900**	9500	270
250 kw Cont.	9,500	4,300	NA	
50 kw Cont., 8 hr., 1 hr.	1,750	790	NA	
10 kw Cont. #1, 2, 3, 4,	724	330	NA	
8 hr. #1, 2, 1 hr.	724	330	NA	
10 kw, 1 hr.	370***	170	NA	

* Power System weight is not expected to change significantly with future generation engines. Weights vary ± 10% depending on the manufacturer and accessories.

** 750 kw requirement consists of three 250 kw units operating in parallel.

*** Portable air cooled unit not for continuous operation.

3.6 Fuel

The cost of gasoline and the quantity consumed by the power system is indicated in the following tabulation

Requirement	Amount Per Year		Average Cost Per Year 10^3 Dollars (1977)	Time Between Deliveries
	10^3 gal	10^3 kg		
750 kw Cont.	644	2,006	329	5 days
250 kw Cont.	215	669	110	5 days
50 kw Cont.	46.0	143	22.4	5 days
50 kw 8 hr.	21.9	68.2	10.7	5 days
50 kw 1 hr.	2.74	8.53	1.86	5 days
10 kw Cont. #1, 2, 3, 4	9.81	30.6	4.70	5 days
10 kw 8 hr. #1, 2	4.67	14.6	2.20	5 days
10 kw 1 hr.	0.58	1.82	0.37	5 days
10 kw 1 hr.	0.77**	2.39	0.38**	5 days

* Cost per year is calculated by dividing the cost of fuel over the life of the system by the life in years. The system life is given in Section 3.3. The systems begin operation in the respective years indicated, and fuel costs are escalated by the method given in Appendix A.

** Portable air cooled unit not intended for continuous operation. Other units are water cooled.

3.7 Environmental Constraints

The environmental constraints of the power system are indicated in the following tabulation:

X amount of uncontrolled emission

Y Amount of pollution which would be emitted with no controls

Z Degree of difficulty in meeting more strict regulations

Key: blank - none

O - minor

◐ - moderate

● - major

Emissions	X	Y	Z
Thermal Discharge (a)	●	-	-
Thermal Discharge (b)	-	-	-
Air Pollution			
CO	◐	-	O
HC	◐	-	O
NO_x	◐	-	◐
SO_x	O	-	-
Particulates	-	-	-
Noise	●	◐	◐
Solid Waste	-	-	-
Chemical Waste	-	-	-
Radioactive Waste	-	-	-

Notes: (a) system is air or water cooled; heat rejected directly to atmosphere.
(b) system is water cooled; heat rejected to body of water or cooling tower. Water source and/or make-up required.

Spark ignition generator sets are normally supplied with exhaust silencers (mufflers) to control the principle noise emissions. Exhaust particulates and SO_x emissions are inherently low when burning gasoline. CO, HC and NO_x are present in the exhaust stream but are not regulated at present. Air cooling or closed cooling systems are used, requiring only makeup water, not a large supply for once through cooling or a cooling tower.

3.8 Location Constraints

The locational limitations of the power system, and the degree of difficulty in overcoming these limitations are indicated in the following tabulation.

— - no difficulty

O - minor difficulty

◐ - major difficulty

● - overriding limitation

LOCATION RESTRAINT	
Water required for cooling	-
Water required for process	-
Manning required during operation	-
Fuel deliveries required	●
Adequate solar insolation required	-
Adequate wind speed required	-
Isolation from population required	-
Electricity required for charging	-

3.9 Operational Constraints

The tabulated operating characteristics are applicable to the power system as indicated.

— - Characteristic not observed in system operation

O - Characteristic has minor effect on system performance

◐ - Characteristic has moderate effect on system performance

● - Characteristic has major effect on system performance

Operational Restraint	
Efficiency reduction at part load	◐
Part load capability limitation	O
Dependence on solar insolation	-
Dependence on wind consistency	-
Overload capacity limitations	O
Delayed response to rapid load changes	O
Life reduction from frequent rapid load changes	O

3.10 System Efficiency

The power system efficiency is indicated in the following tabulation

Requirement	Efficiency %*
750 kw Cont.	18**
250 kw Cont.	18
50 kw Cont., 8 hr., 1 hr.	16
10 kw Cont. #1, 2, 3, 4	15
8 hr. #1, 2, 1 hr.	15
10 kw 1 hr.	12***

* Efficiencies listed are typical for current machines and can vary ± 10% depending on the manufacturer. Efficiencies are not expected to change in the future.

** 750 kw requirement consists of three 250 kw units operating in parallel.

*** Portable air cooled unit not intended for continuous applications. Other units water cooled.

3.11 Type of System

The system type is indicated in the following tabulation.

M - mobile

T - transportable

F - fixed

Time - time for assembly or construction

Requirement	M	T	F	Time
750 kw Cont.		X		3 hrs.
250 kw Cont.	X			
50 kw Cont., 8 hr., 1 hr.	X			
10 kw Cont. #1, 2, 3, 4	X			
8 hr. #1, 2, 1 hr.	X			

No change is expected for future generation systems

3.12 Start-up/Shut-down Time

The start-up and shut-down time for the power system is indicated in the following tabulation.

Requirement	Start-up*	Shut-down
750 kw Cont.	10 sec	10 sec
250 kw Cont.	10 sec	10 sec
50 kw Cont., 8 hr., 1 hr.	10 sec	10 sec
10 kw Cont. #1, 2, 3, 4	10 sec	10 sec
8 hr., #1, 2, 1 hr.	10 sec	10 sec

*The start-up times listed are typical for current generation engines and vary with the manufacturer. No significant changes are expected in the future. Shut-down times can be assumed to be the same as start-up since the same inertial and thermal stress factors apply in each case.

3.13 Growth Potential

The power system is not modular in construction (except for the 750 kw case which utilizes three 250 kw units). As a result, incremental increases in output cannot be achieved without duplicating the original system (except for the 750 kw case).

3.14 Reliability

The tabulated conditions exist in the power system to the extent indicated.

— - Condition does not exist in system

O - Condition exists, but its extent is sufficiently minor as to have minimal effect on system performance or reliability

◐ - Condition exists, and its extent is sufficient to have a moderate effect on system performance or reliability

● - Condition exists and is a governing factor in determining system performance and reliability.

Conditions	
Numerous moving parts	●
High temperature operation	O
High stress levels	O
High radiation level	-
Corrosive attack	O
Thermal cycling	O
Non-modular design	●
Solar insolation required	-
Wind required	-

3.15 Maintenance and Operation

The annual maintenance and operating costs for the power system are listed in the following tabulation.

Requirement	Operation 1977 $/yr	Maintenance 1977 $/yr*	Personnel Required Continuously
750 kw Cont.	1,840	18,860	No
250 kw Cont.	1,225	8,110	No
50 kw Cont.	735	5,050	No
50 kw 8 hr.	350	3,900	No
50 kw 1 hr.	45	510	No
10 kw Cont. #1, 2, 3, 4	440	3,400	No
10 kw 8 hr. #1, 2	210	2,670	No
10 kw 1 hr.	25	350	No
10 kw 1 hr.	25	300**	No

* Includes routine maintenance and overhaul costs. Maintenance costs per kwhr are increased when the unit is started frequently or run at peak ratings.

** Portable air cooled unit not intended for continuous operation. Other units are water cooled.

3.16 Other Energy Production

Thermal energy can be recovered from the engine jacket cooling water, and from the engine exhaust. The temperature of the engine jacket is suitable for the production of hot water, while the exhaust temperature is suitable for the production of saturated or superheated steam.

Requirement	10^6 Btu/hr	10^3 kw Thermal
750 kw Cont.	7.00	2.05
250 kw Cont.	2.33	0.68
50 kw Cont., 8 hr., 1 hr.	0.54	0.16
10 kw Cont. #1, 2, 3, 4,	0.12	0.03
8 hr. #1, 2, 1 hr.	0.12	0.03

The amount of waste heat discharged depends on the thermal efficiency of the power system which is not expected to change significantly in the future. The discharge shown is an average for current machines and will vary $\pm$ 15 percent depending on the manufacturer.

3.17 Availability of Raw Building Materials

The power system is constructed primarily of iron and nickel based metal alloys; no critically short materials are required.

3.18 Development

No development necessary - power system is available now

4.0 REFERENCES

1) Personal Communications with manufacturers.

SECTION VII

FUEL CELL - PHOSPHORIC ACID (CHEMICAL FUEL)

1.0 SYSTEM DESCRIPTION

1.1 System Identification

Energy Converter/Cycle - phosphoric acid fuel cell.

Fuel - Naphtha (first generation), No. 2 distillate (second generation).

Working Fluid - none.

Equivalent Alternate Types - none.

1.2 System Definition

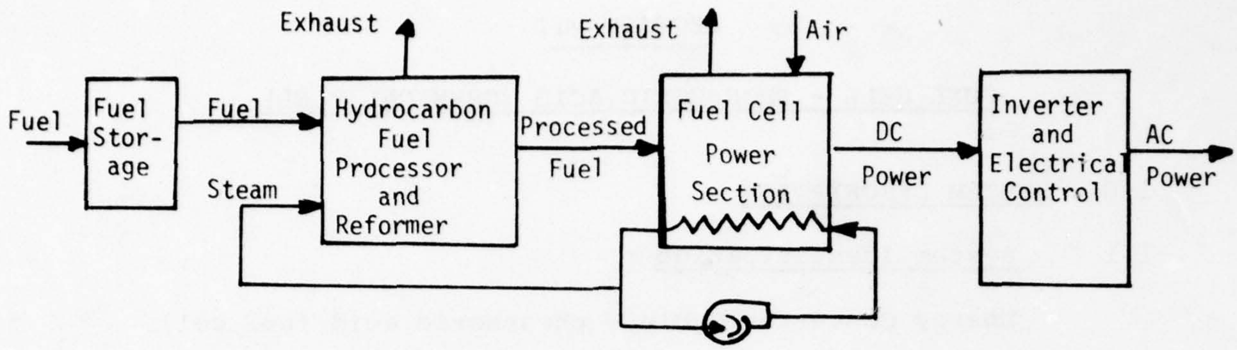
Major Components:

Fuel storage facility.

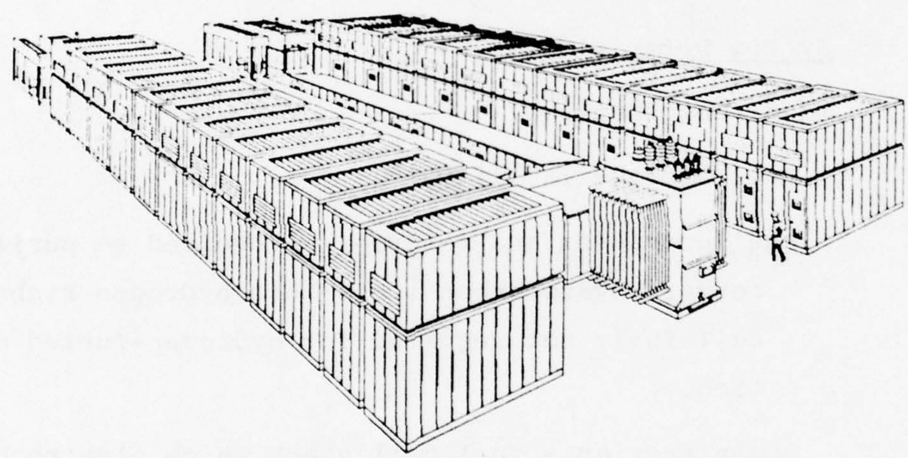
Fuel processor and reformer - required to purify and convert hydrocarbon fuels into hydrogen rich fuel cell fuel; not required for hydrogen-fueled operation.

Power section - fuel cell stack which electrochemically combines hydrogen and oxygen (from air) and generates DC power.

Inverter and electrical control section - required to maintain uniform electrical output under varying load and to convert DC to AC power; inverter not required for DC applications.



1.3 Physical Description



This is an early configuration of a 26 Mw, 1st generation fuel cell power system published by United Technologies Corporation consisting of 24, 1.1 Mw modules covering an area of about ½ acre. A more recent configuration consists of 6, 4.8 Mw modules, which produce 27 Mw a-c (net), and which covers approximately the same area and has the same height. The configuration of a 2nd generation advanced technology plant with the same ratings is not expected to differ significantly.

2.0 LIST OF REQUIREMENTS AND TIME FRAMES

This power system is applicable to the following electrical power requirements as marked. The first date listed indicates the earliest time when the system will be available for purchase. Later dates indicate the point in time when significant improvements are expected.

	Electrical Power Requirements		1977	1980	1985
50 Mw	Continuous	(60 Hz - 3 ø - 13.8 kV)	N/A*	X	X
	1 hour	(60 Hz - 3 ø - 13.8 kV)	N/A	X	X
10 Mw	Continuous	(60 Hz - 3 ø - 4160 V)	N/A	X	X
	8 hour	(60 Hz - 3 ø - 4160 V)	N/A	X	X
	1 hour	(60 Hz - 3 ø - 4160 V)	N/A	X	X
750 kw	Continuous	(60 Hz - 3 ø - 4160 V)	X	N/C**	X
250 kw	Continuous	(60 Hz - 3 ø - 480 V)	X	N/C	X
50 kw	Continuous	(60 Hz - 3 ø - 480 V)	X	N/C	X
	8 hour	(60 Hz - 3 ø - 480 V)	X	N/C	X
	1 hour	(60 Hz - 3 ø - 480 V)	X	N/C	X
10 kw	Continuous #1	(DC - 28 V)	X	N/C	X
	Continuous #2	(60 Hz - 3 ø - 240 V)	X	N/C	X
	Continuous #3	(60 Hz - 1 ø - 240 V)	X	N/C	X
	Continuous #4	(60 Hz - 1 ø - 120 V)	X	N/C	X
	8 hour #1	(DC - 28 V)	X	N/C	X
	8 hour #2	(60 Hz - 3 ø - 240 V)	X	N/C	X
	1 hour	(60 Hz - 3 ø - 240 V)	X	N/C	X

* N/A - These sizes not available as of 1977.

** N/C - These systems are the same as for 1977.

3.0 PARAMETERS

3.1 Acquisition Cost (1977 Dollars)

Requirement	1977	1980	1985
50 Mw Cont.	--	11,000,000	10,000,000
1 hr.	--	11,000,000	10,000,000
10 Mw Cont.	--	2,200,000	2,000,000
8 hr.	--	2,200,000	2,000,000
1 hr.	--	2,200,000	2,000,000
750 kw Cont.	195,000	195,000	168,750
250 kw Cont.	60,000	60,000	56,250
50 kw Cont.	15,000	15,000	12,500
8 hr.	15,000	15,000	12,500
1 hr.	15,000	15,000	12,500
10 kw Cont. #1	3,000	3,000	2,500
#2	3,000	3,000	2,500
#3	3,000	3,000	2,500
#4	3,000	3,000	2,500
10 kw 8 hr. #1	3,000	3,000	2,500
#2	3,000	3,000	2,500
10 kw 1 hr.	3,000	3,000	2,500

All costs are for installed power plants which include a reformer, power section, DC-AC inverter, and associated control instrumentation.

3.2 Life Cycle Cost (1977 Dollars)

The life cycle cost formula applicable to the first and second generation fuel cell power systems is:

LCC = AC + FC + OMC

AC = Acquisition Cost (Section 3.1)

FC = Total Fuel Cost Over System Lifetime (Section 3.6)

OMC = Operation and Maintenance Cost Over System Lifetime (Section 3.15)

	LCC (10^3 \$)			LCC/yr (10^3 \$/yr)		
Requirement	1977	1980	1985	1970	1980	1985
50 Mw Cont.	--	278,980	209,680	--	13,950	10,484
1 hr.	--	27,030	21,950	--	1,352	1,098
10 Mw Cont.	--	55,788	41,950	--	2,789	2,097
8 hr.	--	27,770	21,070	--	1,389	1,053
1 hr.	--	5,406	4,386	--	270	219
750 kw Cont.	3,998.8	4,257	3,191	199.9	212.8	159.6
250 kw Cont.	1,327.5	1,413	1,068	66.4	70.7	53.4
50 kw Cont.	270.9	288.9	217.2	13.5	14.4	10.9
8 hr.	137.1	145.3	110.4	6.85	7.26	5.52
1 hr.	30.3	31.3	24.7	1.52	1.57	1.24
10 kw Cont. #1	54.2	57.6	43.5	2.71	2.88	2.17
#2	54.2	57.6	43.5	2.71	2.88	2.17
#3	54.2	57.6	43.5	2.71	2.88	2.17
#4	54.2	57.6	43.5	2.71	2.88	2.17
10 kw 8 hr. #1	27.4	29.0	22.0	1.37	1.45	1.10
#2	27.4	29.0	22.0	1.37	1.45	1.10
10 kw 1 hr.	6.06	6.26	4.94	0.303	0.313	0.247

Fuel costs are escalated per the method shown in Appendix I.

3.3 Lifetime (years)

Requirement	1977	1980	1985
50 Mw Cont.	-	20	20
1 hr.	-	20	20
10 Mw Cont.	-	20	20
8 hr.	-	20	20
1 hr.	-	20	20
750 kw Cont.	20	20	20
250 kw Cont.	20	20	20
50 kw Cont.	20	20	20
8 hr.	20	20	20
1 hr.	20	20	20
10 kw Cont. #1	20	20	20
#2	20	20	20
#3	20	20	20
#4	20	20	20
10 kw 8 hr. #1	20	20	20
#2	20	20	20
10 kw 1 hr.	20	20	20

3.4 Volume/Size

Requirement	Approximate Area Required*					
	1977		1980		1985	
	sq. ft.	sq. m.	sq. ft.	sq. m.	sq. ft.	sq. m.
50 Mw Cont.	--	--	43,600	4,050	43,600	4,050
1 hr.	--	--	43,600	4,050	43,600	4,050
10 Mw Cont.	--	--	10,000	929	10,000	929
8 hr.	--	--	10,000	929	10,000	929
1 hr.	--	--	10,000	929	10,000	929
750 kw Cont.	900	83.6	900	83.6	900	83.6
250 kw Cont.	300	27.9	300	27.9	300	27.9
50 kw Cont.	60	5.6	60	5.6	60	5.6
8 hr.	60	5.6	60	5.6	60	5.6
1 hr.	60	5.6	60	5.6	60	5.6
10 kw Cont. #1	10	0.93	10	0.93	10	0.93
#2	10	0.93	10	0.93	10	0.93
#3	10	0.93	10	0.93	10	0.93
#4	10	0.93	10	0.93	10	0.93
10 kw 8 hr. #1	10	0.93	10	0.93	10	0.93
#2	10	0.93	10	0.93	10	0.93
10 kw 1 hr.	10	0.93	10	0.93	10	0.93

*Includes an allowance for accessways. Maximum vertical height of components of plants 50 kw and larger is 15 ft. All size power plants can be broken down into road transportable modules with dimensions less than 60'L x 10'W x 13'H (18.3 mL x 3.0 mW x 4.0 mH). Components for 10 Mw and larger sizes are not designed to be air transportable at present. However, design modifications may be possible to remove this restriction.

3.5 Weight

Requirement	System 1977 10^3 lb	System 1977 10^3 kg	System 1980 10^3 lb	System 1980 10^3 kg	System 1985 10^3 lb	System 1985 10^3 kg	Largest Module 1977 10^3 lb	Largest Module 1977 10^3 kg	Largest Module 1980 10^3 lb	Largest Module 1980 10^3 kg	Largest Module 1985 10^3 lb	Largest Module 1985 10^3 kg
50 Mw Cont.	-	-	2,750	1,250	2,750	1,250	-	-	60.0	27.3	60.0	27.3
1 hr.	-	-	2,750	1,250	2,750	1,250	-	-	60.0	27.3	60.0	27.3
10 Mw Cont.	-	-	550	250	550	250	-	-	60.0	27.3	60.0	27.3
8 hr.	-	-	550	250	550	250	-	-	60.0	27.3	60.0	27.3
1 hr.	-	-	550	250	550	250	-	-	60.0	27.3	60.0	27.3
750 kw Cont.	56.3	25.6	56.3	25.6	56.3	25.6	56.3	25.6	56.3	25.6	56.3	25.6
250 kw Cont.	18.8	8.5	18.8	8.5	18.8	8.5	18.8	8.5	18.8	8.5	18.8	8.5
50 kw Cont.	5.00	2.3	5.00	2.3	5.00	2.3	5.00	2.3	5.00	2.3	5.00	2.3
8 hr.	5.00	2.3	5.00	2.3	5.00	2.3	5.00	2.3	5.00	2.3	5.00	2.3
1 hr.	5.00	2.3	5.00	2.3	5.00	2.3	5.00	2.3	5.00	2.3	5.00	2.3
10 kw Cont. #1	1.00	0.454	1.00	0.454	1.00	0.454	1.00	0.454	1.00	0.454	1.00	0.454
#2	1.00	0.454	1.00	0.454	1.00	0.454	1.00	0.454	1.00	0.454	1.00	0.454
#3	1.00	0.454	1.00	0.454	1.00	0.454	1.00	0.454	1.00	0.454	1.00	0.454
#4	1.00	0.454	1.00	0.454	1.00	0.454	1.00	0.454	1.00	0.454	1.00	0.454
8 hr. #1	1.00	0.454	1.00	0.454	1.00	0.454	1.00	0.454	1.00	0.454	1.00	0.454
#2	1.00	0.454	1.00	0.454	1.00	0.454	1.00	0.454	1.00	0.454	1.00	0.454
1 hr.	1.00	0.454	1.00	0.454	1.00	0.454	1.00	0.454	1.00	0.454	1.00	0.454

3.6 Fuel

A. Fuel Utilization

Requirement	Amount Per Year						Average Cost Per Year (10^3 1977 $)			Time Between Deliveries
	1977		1980		1985					
	10^3 lbm	10^3 kg	10^3 lbm	10^3 kg	10^3 lbm	10^3 kg	1977	1980	1985	
50 Mw Cont.	-	-	142,570	64,658	117,923	53,577	-	12,847	9,432	2 wks
1 hr.	-	-	8,486	3,849	7,019	3,189	-	765	561	2 wks
10 Mw Cont.	-	-	28,514	12,932	23,585	10,715	-	2,569	1,887	2 wks
8 hr.	-	-	13,578	6,158	11,231	5,103	-	1,223	898	2 wks
1 hr.	-	-	1,697	770	1,404	638	-	153	112	2 wks
750 kw Cont.	2,139	970	2,139	970	1,769	804	180	193	141	5 days
250 kw Cont.	713	323	713	323	590	268	60.0	64.3	47.2	5 days
50 kw Cont.	143	64.9	143	64.9	118	53.6	12.0	12.9	9.44	5 days
8 hr.	67.9	30.8	67.9	30.8	56.2	25.5	5.71	6.12	4.50	
1 hr.	8.5	3.9	8.5	3.9	7.0	3.2	0.715	0.766	0.560	5 days
10 kw Cont.#1	28.5	12.9	28.5	12.9	23.6	10.7	2.40	2.57	1.89	5 days
#2	28.5	12.9	28.5	12.9	23.6	10.7	2.40	2.57	1.89	
#3	28.5	12.9	28.5	12.9	23.6	10.7	2.40	2.57	1.89	5 days
#4	28.5	12.9	28.5	12.9	23.6	10.7	2.40	2.57	1.89	5 days
8 hr.#1	13.6	6.2	13.6	6.2	11.2	5.1	1.14	1.22	0.896	5 days
#2	13.6	6.2	13.6	6.2	11.2	5.1	1.14	1.22	0.896	5 days
1 hr.	1.70	0.77	1.70	0.77	1.40	0.64	0.143	0.153	0.112	5 days

B. Alternate Fuels

Use of low sulfur naphtha is assumed for all systems coming on line in 1977 and 1980, while use of No. 2 distillate is assumed for all second generation advanced technology units coming on line in 1985. Note, however, that natural gas is specified by the major manufacturer as the primary fuel for the 50 kw and smaller units developed as of 1977. Conversion to low sulfur naphtha should not present any major obstacles. Large size units will also be able to operate using natural gas in 1980, but are primarily being developed to use liquid fuel. Advanced technology reformer developments are expected to permit operation with higher sulfur distillate fuels, such as No. 2 and diesel oils, as included for the second generation systems. Methyl fuel is also attractive if available.

Another alternate fuel is hydrogen. Use of hydrogen does away with the need for the reformer and can thus reduce the fuel cell system capital cost by as much as 25 percent. However, since hydrogen is not a primary fuel, its cost will reflect the additional cost of primary fuel processing. Also, more expensive on-site storage facilities will be required than for distillate fuels.

C. Fuel Availability

The commercial supply of naphtha is based on petrochemical feedstocks. By 1980, the non-fuel cell demand for petrochemical naphtha is expected to increase to 200×10^6 bbl/year. Assuming low fuel cell implementation, the added demand may be met with an accompanying increase in prices. Assuming high fuel cell implementation, the added demand will not be met without severe price increases, if at all. Availability of natural gas is also expected to decline sharply over the next decade. Flexibility in fuel choice is, therefore, being developed for future fuel cell systems.

Hydrogen is presently thought to be the long-term fuel solution. Its wide utilization will require development of more efficient production methods, as well as special transmission, distribution, and storage systems.

3.7 Environmental Constraints

The environmental constraints of the power system are indicated in the following tabulation:

X amount of uncontrolled emission

Y Amount of pollution which would be emitted with no controls

Z Degree of difficulty in meeting more strict regulations

Key: blank - none

0 - minor

◐ - moderate

● - major

Emissions	X	Y	Z
Thermal Discharge (a)	●	-	-
Thermal Discharge (b)	-	-	-
Air Pollution			
CO	-	-	-
HC	-	-	-
NO_x	-	-	-
SO_x	-	-	-
Particulates	-	-	-
Noise	0	0	◐
Solid Waste	-	-	-
Chemical Waste	-	-	-
Radioactive Waste	-	-	-

Notes: (a) system is air or water cooled; heat rejected directly to atmosphere.
(b) system is water cooled; heat rejected to body of water or cooling tower. Water source and/or make-up required.

3.8 Location Constraints

The locational limitations of the power system, and the degree of difficulty in overcoming these limitations are indicated in the following tabulation.

— - no difficulty

O - minor difficulty

◐ - major difficulty

● - overriding limitation

LOCATION RESTRAINT	
Water required for cooling	-
Water required for process	-
Manning required during operation	-
Fuel deliveries required	●
Adequate solar insolation required	-
Adequate wind speed required	-
Isolation from population required	-
Electricity required for charging	-

3.9 Operational Constraints

The tabulated operating characteristics are applicable to the power system as indicated.

— - Characteristic not observed in system operation

O - Characteristic has minor effect on system performance

◐ - Characteristic has moderate effect on system performance

● - Characteristic has major effect on system performance

Operational Restraint	
Efficiency reduction at part load	-
Part load capability limitation	-
Dependence on solar insolation	-
Dependence on wind consistency	-
Overload capacity limitations	-
Delayed response to rapid load changes	-
Life reduction from frequent rapid load changes	-

3.10 System Efficiency

Requirement	Full-Load Efficiency (%)			Maximum Part-Load Efficiency (%)		
	1977	1980	1985	1977	1980	1985
50 Mw Cont.	--	36.7	45.5	--	39.2	47.4
1 hr.	--	36.7	45.5	--	39.2	47.4
10 Mw Cont.	--	36.7	45.5	--	39.2	47.4
8 hr.	--	36.7	45.5	--	39.2	47.4
1 hr.	--	36.7	45.5	--	39.2	47.4
750 kw Cont.	36.7	36.7	45.5	39.2	39.2	47.4
250 kw Cont.	36.7	36.7	45.5	39.2	39.2	47.4
50 kw Cont.	36.7	36.7	45.5	39.2	39.2	47.4
8 hr.	36.7	36.7	45.5	39.2	39.2	47.4
1 hr.	36.7	36.7	45.5	39.2	39.2	47.4
10 kw Cont. #1	36.7	36.7	45.5	39.2	39.2	47.4
#2	36.7	36.7	45.5	39.2	39.2	47.4
#3	36.7	36.7	45.5	39.2	39.2	47.4
#4	36.7	36.7	45.5	39.2	39.2	47.4
10 kw 8 hr. #1	36.7	36.7	45.5	39.2	39.2	47.4
#2	36.7	36.7	45.5	39.2	39.2	47.4
10 kw 1 hr.	36.7	36.7	45.5	39.2	39.2	47.4

3.11 Type of System

The following chart applies to both the 1st and 2nd generation fuel cell power systems.

Requirement	M	T	F	Time Install.	Time Lead
50 Mw Cont.			X	3 mo.	2 yr.
1 hr.			X	3 mo.	2 yr.
10 Mw Cont.			X	2 mo.	2 yr.
8 hr.			X	2 mo.	2 yr.
1 hr.			X	2 mo.	2 yr.
750 kw Cont.			X	1 mo.	1 yr.
250 kw Cont.			X	1 mo.	1 yr.
50 kw Cont.		X		1 wk.	6 mo.
8 hr.		X		1 wk.	6 mo.
1 hr.		X		1 wk.	6 mo.
10 kw Cont. #1	X			1 day	6 mo.
#2	X			1 day	6 mo.
#3	X			1 day	6 mo.
#4	X			1 day	6 mo.
10 kw 8 hr. #1	X			1 day	6 mo.
#2	X			1 day	6 mo.
10 kw 1 hr.	X			1 day	6 mo.

M = Mobile

T = Transportable

F = Fixed

3.12 Start-up/Shutdown Times

Requirement	Start-up/Shutdown (hr)*		
	1977	1980	1985
50 Mw Cont.	-	4/1	4/1
1 hr.	-	4/1	4/1
10 Mw Cont.	-	4/1	4/1
8 hr.	-	4/1	4/1
1 hr.	-	4/1	4/1
750 kw Cont.	3/0.75	3/0.75	3/0.75
250 kw Cont.	3/0.75	3/0.75	3/0.75
50 kw Cont.	1/0.25	1/0.25	1/0.25
8 hr.	1/0.25	1/0.25	1/0.25
1 hr.	1/0.25	1/0.25	1/0.25
10 kw Cont. #1	0.5/0.13	0.5/0.13	0.5/0.13
#2	0.5/0.13	0.5/0.13	0.5/0.13
#3	0.5/0.13	0.5/0.13	0.5/0.13
#4	0.5/0.13	0.5/0.13	0.5/0.13
10 kw 8 hr. #1	0.5/0.13	0.5/0.13	0.5/0.13
#2	0.5/0.13	0.5/0.13	0.5/0.13
10 kw 1 hr.	0.5/0.13	0.5/0.13	0.5/0.13

*From 21.1°C (70°F) ambient.

3.13 Growth Potential

The growth potential of these fuel cell systems is excellent due to their high degree of modularization. Increments can be simply made in almost any size required and with short lead time.

These fuel cell systems are ideally suited for 1 kw and 100 W applications.

3.14 Reliability

The tabulated conditions exist in the power system to the extent indicated.

— - Condition does not exist in system

O - Condition exists, but its extent is sufficiently minor as to have minimal effect on system performance or reliability

◐ - Condition exists, and its extent is sufficient to have a moderate effect on system performance or reliability

● - Condition exists and is a governing factor in determining system performance and reliability.

Conditions	
Numerous moving parts	-
High temperature operation	-
High stress levels	-
High radiation level	-
Corrosive attack	0
Thermal cycling	-
Non-modular design	-
Solar insolation required	-
Wind required	-

3.15 Maintenance and Operation

Requirement	Cost/Yr (1977 $/Yr)			Personnel Required Continuously
	1977	1980	1985	
50 Mw Cont.	-	551,880	551,880	No
1 hr.	-	36,500	36,500	No
10 Mw Cont.	-	110,376	110,376	No
8 hr.	-	55,480	55,480	No
1 hr.	-	7,300	7,300	No
750 kw Cont.	10,118	10,118	10,188	No
250 kw Cont.	3,373	3,373	3,373	No
50 kw Cont.	797.2	797.2	797.2	No
8 hr.	394.2	394.2	394.2	No
1 hr.	51.1	51.1	51.1	No
10 kw Cont. #1	159.4	159.4	159.4	No
#2	159.4	159.4	159.4	No
#3	159.4	159.4	159.4	No
#4	159.4	159.4	159.4	No
10 kw 8 hr. #1	78.8	78.8	78.8	No
#2	78.8	78.8	78.8	No
10 kw 1 hr.	10.2	10.2	10.2	No

Maintenance Requirement:

For power plants 250 kw and larger, maintenance will consist of periodic overhaul of individual modules. Complete plant shutdown will not be required. For smaller power plants, single modules will be employed in most cases, and complete plant shutdown or replacement will be required. Maintenance will be carried out off site at the following time intervals:

Refurbishment of fuel cell stack	- 5 years
Overhaul of reformer	- 10 years
Overhaul of inverter	- 20 years

For the 10 Mw and 50 Mw plants, a portable crane and about four people will be required to maneuver the modules. For the 750 kw and smaller units, three people should be sufficient.

3.16 Other Energy Production

Thermal energy is available primarily in the form of fuel cell stack heat. Its temperature is suitable for the production of low pressure saturated steam and hot water.

Requirement	1977 10^3 Btu/hr	1977 kw Thermal	1980 10^3 Btu/hr	1980 kw Thermal	1985 10^3 Btu/hr	1985 kw Thermal
50 Mw Cont.	-	-	155,590	45,600	108,100	31,680
1 hr.	-	-	155,590	45,600	108,100	31,680
10 Mw Cont.	-	-	31,120	9,120	21,150	6,200
8 hr.	-	-	31,120	9,120	21,150	6,200
1 hr.	-	-	31,120	9,120	21,150	6,200
750 kw Cont.	2,334	684.0	2,334	684.0	1,587	465
250 kw Cont.	778.0	228.0	778.0	228.0	528.9	155
50 kw Cont.	155.6	45.6	155.6	45.6	105.8	31.0
8 hr.	155.6	45.6	155.6	45.6	105.8	31.0
1 hr.	155.6	45.6	155.6	45.6	105.8	31.0
10 kw Cont. #1	31.1	9.12	31.1	9.12	21.2	6.20
#2	31.1	9.12	31.1	9.12	21.2	6.20
#3	31.1	9.12	31.1	9.12	21.2	6.20
#4	31.1	9.12	31.1	9.12	21.2	6.20
10 kw 8 hr. #1	31.1	9.12	31.1	9.12	21.2	6.20
#2	31.1	9.12	31.1	9.12	21.2	6.20
10 kw 1 hr.	31.1	9.12	31.1	9.12	21.2	6.20

3.17 Availability of Raw Building Materials

The major critical material is platinum which is used as a catalytic electrode coating in the low temperature fuel cells. Large scale implementation of fuel cell power plants could put a severe burden on platinum supplies. Research is being carried out, however, to reduce the amount of platinum required and to find alternative less expensive, more plentiful materials for the 2nd generation advanced technology systems.

3.18 Development

Development Program Cost and Duration

Requirement	Cost (10^3 1977 $)		Time (Years)	
	1980	1985	1980	1985
50 Mw Cont.	60,000	250,000	3	8
1 hr.	(1)	(1)	(1)	(1)
10 Mw Cont.	(1)	(1)	(1)	(1)
8 hr.	(1)	(1)	(1)	(1)
1 hr.	(1)	(1)	(1)	(1)
750 kw Cont.	(1)	(1)	(1)	(1)
250 kw Cont.	(1)	(1)	(1)	(1)
50 kw Cont.	(1)	(1)	(2)	(1)
8 hr.	(1)	(1)	(2)	(1)
1 hr.	(1)	(1)	(2)	(1)
10 kw Cont. #1	(1)	(1)	(2)	(1)
#2	(1)	(1)	(2)	(1)
#3	(1)	(1)	(2)	(1)
#4	(1)	(1)	(2)	(1)
10 kw 8 hr. #1	(1)	(1)	(2)	(1)
#2	(1)	(1)	(2)	(1)
10 kw 1 hr.	(1)	(1)	(2)	(1)

(1) Cost and time of development of this size plant is included in that of 50 Mw plant.

(2) This size plant is available as of 1977.

Improvements are required primarily to develop new forms of construction materials, catalysts, and components in order to reach cost goals. Extensive engineering development and demonstration remains before overall economics, operating reliability, and durability are established.

The probability of success in developing the first and second generation systems is high.

Major program in progress: Joint EPRI-ERDA-United Technologies, Inc.-Consolidated Edison of New York project to design, fabricate, install, and test a 4.5 Mw (a-c) module building block.

Technology status: 1 kw units have been built and are available, although costly; 12.5 kw units have been built and tested in utility systems; 40 kw units have been built and are being tested; a 4.5 Mw (a-c) unit is being developed, as noted in Item 3.19 D, as a building block for larger size systems; intermediate sizes are expected to be routine interpolations between the 40 kw and 4.5 Mw sizes.

4.0 REFERENCES

1. "ERDA/EPRI Fuel Cell Seminar," June 1976

2. "National Fuel Cell Seminar," June 1977

3. "National Benefits Associated with Commmercial Applications of Fuel Cell Powerplants," Power Systems Division, United Technologies Corporation, ERDA 76-54, February 1976

4. "Energy Fact Book 1976," prepared by Tetra Tech, Inc., for the U. S. Navy, February 1976

5. "Background Information on Fuel Cells," prepared by the National Aeronautics and Space Administration for ERDA, July 1975

6. "Comparing New Technologies for the Electric Utilities," Draft Final Report (Revision A), ERDA 76-141

7. "EPRI Journal," No. 3, April 1976

8. "EPRI Journal," No. 1, January/February 1977

9. "Integrated Coal Gasifier/Molten Carbonate Fuel Cell Powerplant Conceptual Design and Implementation Assessment," Energy Conversion Alternatives Study (ECAS), United Technologies Phase II Final Report, NASA CR-134955, FCR-0237

SECTION VIII

STEAM TURBINE GENERATOR - COAL
(CHEMICAL FUEL)

1.0 SYSTEM DESCRIPTION

1.1 System Identification

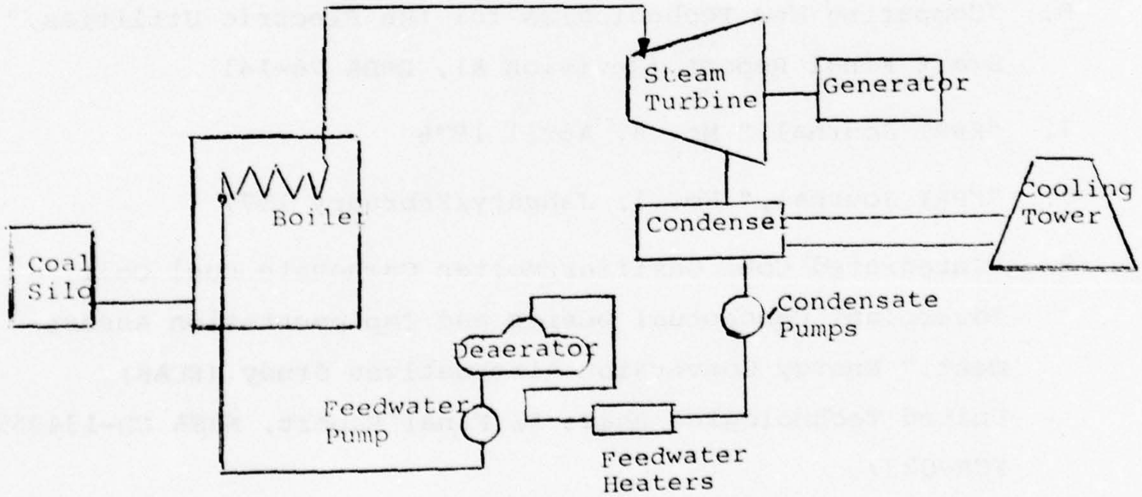
Energy Converter/Cycle - steam turbine/closed Rankine cycle

Fuel - low sulfur coal

Working Fluid - water

Equivalent Alternate Types - none

1.2 System Definition



The major components of this plant consist of the coal handling equipment, boiler and emission controls, steam turbine generator, condenser and cooling water system, condensate, feedwater and other auxiliary systems. The plant is stationary and consists of the following major structures.

a. Turbine Generator Building

b. Boiler Structure

c. Coal Silo

d. Cooling Towers and Circulating and Service Water Pumphouses

e. Miscellaneous Auxiliary Buildings

Off-site ash disposal is assumed.

This type of system must be constructed on a fixed site. It cannot be purchased as a pre-packaged system Various components are required which are manufactured by a number of different companies. Therefore, a significant engineering effort is required to coordinate the system design and construction. The details of the system depend upon site conditions. Therefore, the system must be engineered for each site.

1.3 Physical Description

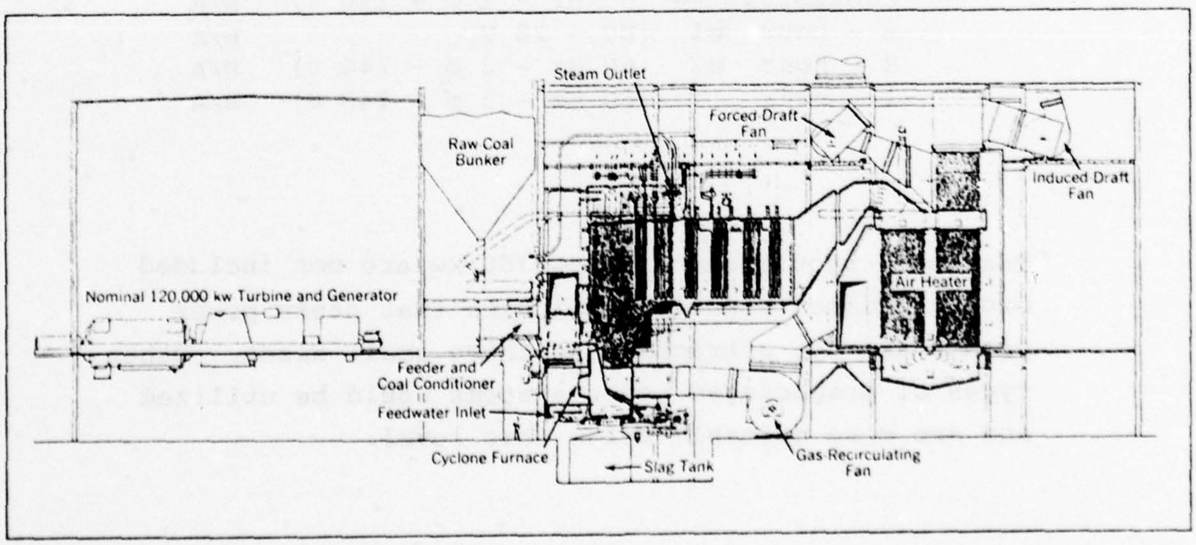


Figure 13. Typical design of a 120 MW coal fired steam power plant - Babcock & Wilcox Co.

2.0 LIST OF REQUIREMENTS AND TIME FRAMES

This power system is applicable to the following electrical power requirements as marked. All data is based upon technology which is available in 1977.

	ELECTRICAL POWER REQUIREMENTS		1977
50 Mw	Continuous	(60 Hz - 3 ø - 13.8 kV)	X
	1-hour	(60 Hz - 3 ø - 13.8 kV)	X
10 MW	Continuous	(60 Hz - 3 ø - 4160 V)	X
	8 - hour	(60 Hz - 3 ø - 4160 V)	X
	1 - hour	(60 Hz - 3 ø - 4160 V)	X
750 kw	Continuous	(60 Hz - 3 ø - 4160 V)	X
250 kw	Continuous	(60 Hz - 3 ø - 480 V)	N/A*
50 kw	Continuous	(60 Hz - 3 ø - 480 V)	N/A
	8 - hour	(60 Hz - 3 ø - 480 V)	N/A
	1 - hour	(60 Hz - 3 ø - 480 V)	N/A
10 kw	Continuous #1	(DC - 28 V)	N/A
	Continuous #2	(60 Hz - 3 ø - 240 V)	N/A
	Continuous #3	(60 Hz - 1 ø - 240 V)	N/A
	Continuous #4	(60 Hz - 1 ø - 120 V)	N/A
	8 - hour #1	(DC - 28 V)	N/A
	8 - hour #2	(60 Hz - 3 ø - 240 V)	N/A
	1 - hour	(60 Hz - 3 ø - 240 V)	N/A

* The power requirements below 750 kw are not included because common practice indicates that steam power plants are not attractive in these small sizes. Other types of prepackaged power systems would be utilized and are more suitable below this level.

3.0 PARAMETERS

3.1 Acquisition Cost (1977 Dollars)

Requirement	1977
50 Mw Cont.	36,208,000
1 hr.	33,000,000
10 Mw Cont.	11,268,000
8 hr.	11,268,000
1 hr.	10,000,000
750 kw Cont.	2,764,000

Acquisition Cost Breakdown:

	50 MWe Plant	10 MWe Plant	750 MWe Plant
Turbine Plant	7,995,000	2,799,000	547,000
Coal Fired Boiler Plant	16,640,000	3,166,000	757,000
Engineering and Construction Management	5,538,000	3,425,000	1,000,000
Contingency @ 20%	6,035,000	1,878,000	460,000
Total Costs	36,208,000	11,268,000	2,764,000

3.2 Life Cycle Cost (1977 Dollars)

The life cycle cost (LCC) formula applicable to this system is:

LCC = AC + FC + OMC

Where AC = Acquisition Cost (See Section 3.1)

FC = Total Fuel Cost Over System Lifetime (See Section 3.6)

OMC = Operation and Maintenance Cost over System Lifetime (See Section 3.15)

Requirement	LCC (1977)	LCC/yr (1977)
50 Mw Cont.	247,000,000	6,175,000
1 hr.	61,144,000	1,528,000
10 Mw Cont.	85,800,000	2,145,000
8 hr.	52,468,000	1,320,000
1 hr.	22,652,000	566,000
750 kw Cont.	7,664,000	192,000

3.3 Lifetime (Years)

Requirement	1977
50 Mw Cont.	40
1 hr.	40
10 Mw Cont.	40
8 hr.	40
1 hr.	40
750 kw Cont.	40

3.4 Volume/Size

Requirement	Approximate Land Area Required	
	sq. ft.	sq. m.
50 Mw Cont.	170,000	15,800
1 hr.	100,000	9,300
10 Mw Cont.	76,000	71,000
8 hr.	60,000	5,600
1 hr.	50,000	4,600
750 kw Cont.	21,000	1,950

Land area requirements include land area for coal handling and storage.

3.5 Weight

Weight is not a relevant parameter for this type of system. Plant cannot be air lifted to provide ground power to remote sites. Plant must be constructed at a fixed site.

3.6 Fuel

A. Fuel Utilization

Requirement	Amount Per Year tons	kg	Average Cost Per Year (1977 Dollars)	Time Between Deliveries
50 Mw Cont.	170,000	154,000,000	4,375,800	Weekly
1 hr.	9,800	8,900,000	253,600	Monthly
10 Mw Cont.	43,200	39,200,000	1,113,500	Weekly
8 hr.	20,600	18,300,000	530,000	Monthly
1 hr.	2,580	2,300,000	66,300	Monthly
750 kw Cont.	3,240	7,900,000	83,500	Monthly

Cost of fuel is highly dependent upon location of plant.

B. Alternate Fuels

High Sulfur Coal: Fuel cost is comparable to that of low sulfur coal. However, acquisition cost is much higher due to necessity for air pollution control equipment required to meet environmental regulations for sulfur oxide emissions.

C. Fuel Availability

Fuel availability is not a problem. Adequate coal supplies are available in the United States.

3.7 Environmental Constraints

The environmental constraints of the power system are indicated in the following tabulation:

X amount of uncontrolled emission

Y Amount of pollution which would be emitted with no controls

Z Degree of difficulty in meeting more strict regulations

Key: blank - none
0 - minor
◐ - moderate
● - major

Emissions	X	Y	Z
Thermal Discharge (a)	◐	-	-
Thermal Discharge (b)	●	●	●
Air Pollution			
CO	0	-	0
HC	0	-	0
NO_x	◐	-	◐
SO_x	◐	-	●
Particulates	●	●	●
Noise	◐	◐	◐
Solid Waste	●	-	●
Chemical Waste	0	-	0
Radioactive Waste	-	-	-

Notes: (a) system is air or water cooled; heat rejected directly to atmosphere.
(b) system is water cooled; heat rejected to body of water or cooling tower. Water source and/or make-up required.

3.8 Location Constraints

The locational limitations of the power system, and the degree of difficulty in overcoming these limitations are indicated in the following tabulation.

— - no difficulty

O - minor difficulty

◐ - major difficulty

● - overriding limitation

LOCATION RESTRAINT	
Water required for cooling	◐
Water required for process	◐
Manning required during operation	●
Fuel deliveries required	●
Adequate solar insolation required	–
Adequate wind speed required	–
Isolation from population required	–
Electricity required for charging	–

3.9 Operational Constraints

The tabulated operating characteristics are applicable to the power system as indicated.

— - Characteristic not observed in system operation

O - Characteristic has minor effect on system performance

◐ - Characteristic has moderate effect on system performance

● - Characteristic has major effect on system performance

Operational Restraint	
Efficiency reduction at part load	◐
Part load capability limitation	◐
Dependence on solar insolation	–
Dependence on wind consistency	–
Overload capacity limitations	◐
Delayed response to rapid load changes	◐
Life reduction from frequent rapid load changes	◐

3.10 System Efficiency

Requirement	% 1977
50 Mw Cont.	28
1 hr.	28
10 Mw Cont.	22
8 hr.	22
1 hr.	22
750 kw Cont.	20

3.11 Type of System

Requirement	Mobile	Trans-portable	Fixed	Construction Time (years)
50 Mw Cont.			x	3.5
1 hr.			x	3.5
10 Mw Cont.			x	3.5
8 hr.			x	3.5
1 hr.			x	3.5
750 kw Cont.			x	2.0

3.12 Start-up/Shut-down Times

Requirement	Start-up*	Shut-down
50 Mw Cont.	8 hr.	8 hr.
1 hr.	8 hr.	8 hr.
10 Mw Cont.	8 hr.	8 hr.
8 hr.	8 hr.	8 hr.
1 hr.	8 hr.	8 hr.
750 kw Cont.	4 hr.	4 hr.

*Assuming cold start

3.13 Growth Potential

This type of power plant is non-modular by nature with the result that growth in capacity can be achieved only by adding an additional boiler and turbine. If growth is planned from the beginning, equipment can be oversized for future additional capacity.

3.14 Reliability

The tabulated conditions exist in the power system to the extent indicated.

— - Condition does not exist in system

O - Condition exists, but its extent is sufficiently minor as to have minimal effect on system performance or reliability

◐ - Condition exists, and its extent is sufficient to have a moderate effect on system performance or reliability

● - Condition exists and is a governing factor in determining system performance and reliability.

Conditions	
Numerous moving parts	●
High temperature operation	O
High stress levels	O
High radiation level	–
Corrosive attack	O
Thermal cycling	◐
Non-modular design	●
Solar insolation required	–
Wind required	–

3.15 Maintenance and Operation

Requirement	Cost Per Year	Overhaul Duration (wks/yr)	Personnel Required Continuously
50 Mw Cont.	900,000	4	Yes
1 hr.	450,000	1	No
10 Mw Cont.	750,000	4	Yes
8 hr.	500,000	2	No
1 hr.	250,000	1	No
750 kw Cont.	39,000	4	Yes

Operation and Maintenance Requirements:

An operating crew must be in constant attendence during operation of the power plant.

A maintenance team must be available at the site to perform routine power plant maintenance.

Maintenance crew would consist of machinists, instrument technicians, electricians, welders, etc.

3.16 Other Energy Production

Requirement	10^6 Btu/hr	10^3 kw thermal
50 Mw Cont.	263	77.1
1 hr.	263	77.1
10 Mw Cont.	72.6	21.3
8 hr.	72.6	21.3
1 hr.	72.6	21.3
750 kw Cont.	6.00	1.76

For a power plant of this type, thermal energy is normally discharged to the environment in two forms: (a) low temperature condenser heat rejection to a body of water or to the atmosphere via wet or dry cooling towers and (b) boiler exhaust gases at high temperatures directly to the atmosphere via a chimney. The electrical power output of the plant is maximized by making the temperatures of the thermal discharges as low as practicable. To utilize the exhaust gases for heating purposes, the gases can be diverted to the areas requiring heat with the use of an intermediate heat exchanger. The exhaust gases leaving the stack can provide approximately 10 percent of the boiler thermal output for other uses. Temperatures are suitable for the production of saturated or superheated steam.

3.17 Availability of Raw Building Materials

Raw building materials are readily available for this type of power plant.

3.18 Development

No development is required for this type of power plant as all the equipment utilized is commercially available. No risk is involved as proven technology is utilized in the design and construction of this plant.

4.0 References

(1) Types and Characteristics of Industrial Dual Purpose Power Plants, FEA Contract CRO 4-60712-00, by Burns and Roe, dated January 4, 1976.

(2) ERDA 76-141, Comparing New Technologies for the Electric Utilities, dated 12/9/76 Draft Final Report

(3) Report on Equipment Availability for the Thirteen-Year Period, 1960-1972, EEI Publication 73-46, issued December 1973.

SECTION IX

STEAM TURBINE GENERATOR - OIL/GAS

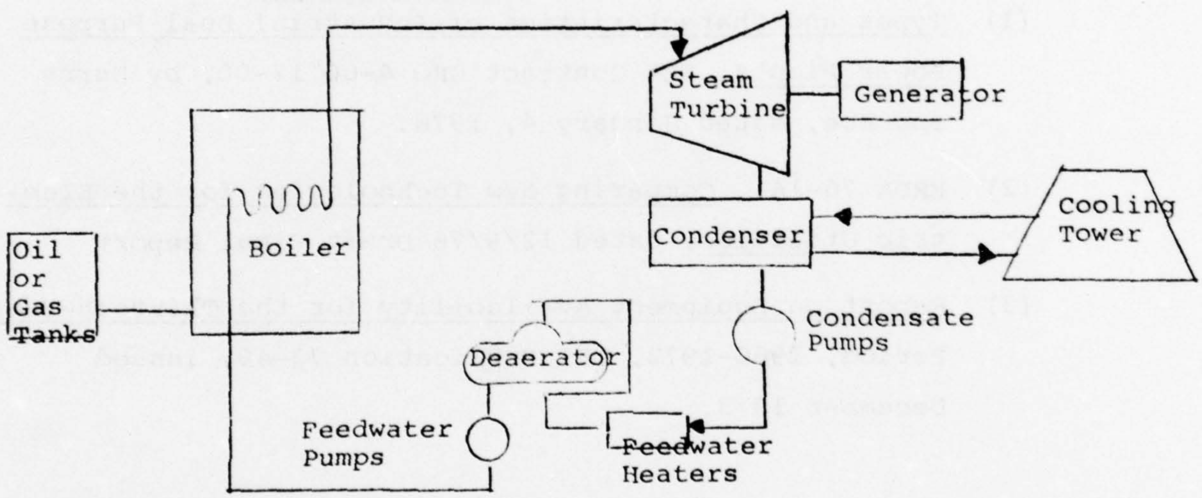
(CHEMICAL FUEL)

1.0 SYSTEM DESCRIPTION

1.1 System Identification

Fuel Converter - Boiler
Energy Converter/Cycle - Steam turbine/closed rankine cycle
Fuel - Oil or natural gas
Working Fluid - Water
Equivalent Alternate Type - None

1.2 System Definition



The major components of this plant consist of the boiler, steam turbine generator, condenser and cooling water system, condensate feedwater and other auxiliary systems. The plant is stationary and consists of the following major structures.

a. Turbine Generator Building
b. Boiler Structure
c. Outdoor Fuel Tanks
d. Cooling Towers and Circulating and Service Water Pumphouses
e. Miscellaneous Auxiliary Buildings

This type of system must be constructed on a fixed site. It cannot be purchased as a pre-packaged system. Various components are required which are manufactured by a number of different companies. Therefore, a significant engineering effort is required to coordinate the system design and construction. The details of the systems depend upon site conditions. Therefore, the system must be engineered for each site.

1.3 Physical Description

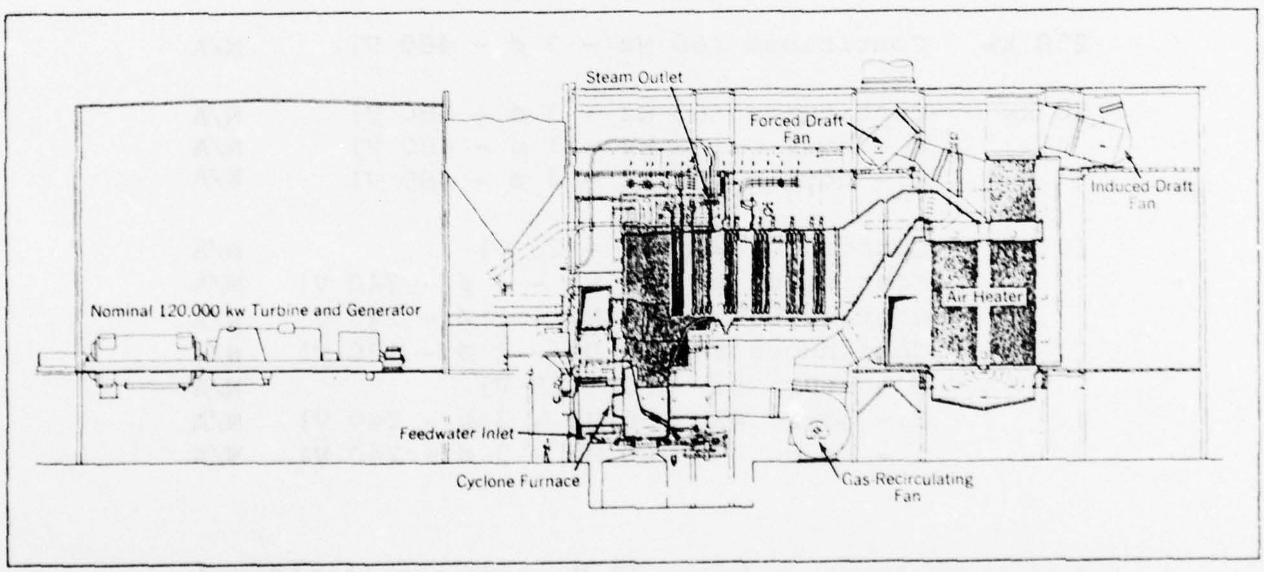


Figure 14. Typical design of a 120 MW oil or gas fired steam power plant - Babcock & Wilcox Co.

2.0 LIST OF REQUIREMENTS AND TIME FRAMES

This power system is applicable to the following electrical power requirements as marked. All data is based on technology which is available in 1977.

	ELECTRICAL POWER REQUIREMENTS	1977
50 Mw	Continuous (60 Hz - 3 ø - 13.8 kV)	X
	1-hour (60 Hz - 3 ø - 13.8 kV)	X
10 MW	Continuous (60 Hz - 3 ø - 4160 V)	X
	8 - hour (60 Hz - 3 ø - 4160 V)	X
	1 - hour (60 Hz - 3 ø - 4160 V)	X
750 kw	Continuous (60 Hz - 3 ø - 4160 V)	N/A
250 kw	Continuous (60 Hz - 3 ø - 480 V)	N/A
50 kw	Continuous (60 Hz - 3 ø - 480 V)	N/A
	8 - hour (60 Hz - 3 ø - 480 V)	N/A
	1 - hour (60 Hz - 3 ø - 480 V)	N/A
10 kw	Continuous #1 (DC - 28 V)	N/A
	Continuous #2 (60 Hz - 3 ø - 240 V)	N/A
	Continuous #3 (60 Hz - 1 ø - 240 V)	N/A
	Continuous #4 (60 Hz - 1 ø - 120 V)	N/A
	8 - hour #1 (DC - 28 V)	N/A
	8 - hour #2 (60 Hz - 3 ø - 240 V)	N/A
	1 - hour (60 Hz - 3 ø - 240 V)	N/A

Power requirements below 10 Mw were not considered since common practice indicates that steam power plants are not attractive in these small sizes. Other systems such as diesel engines and gas turbines are more practical below this level.

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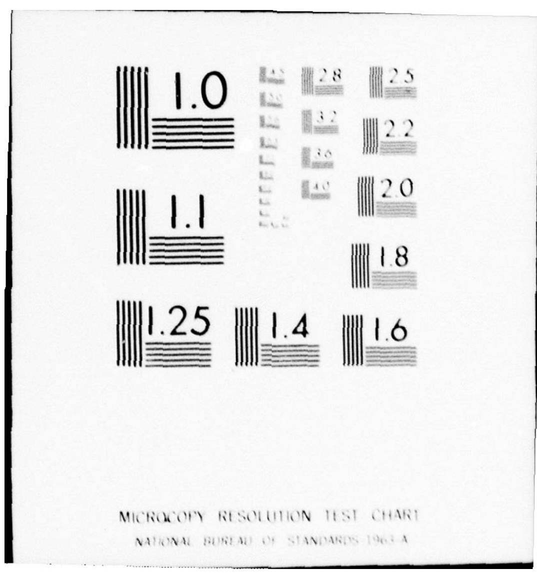
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4.0
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

3.0 PARAMETERS

3.1 Acquisition Cost (1977 Dollars)

Requirement	1977
50 Mw Cont.	29,400,000
1 hr.	29,400,000
10 Mw Cont.	9,530,000
8 hr.	9,530,000
1 hr	9,530,000

Acquisition Cost Breakdown

	50 MWe Plant	10 MWe Plant
Turbine Plant	8,000,000	2,800,000
Oil or Gas Fired Boiler Plant	11,400,000	1,830,000
Engineering and Construction Management	5,100,000	3,300,000
Contingency @ 20%	4,900,000	1,600,000
Total Costs	29,400,000	9,530,000

Note: Costs are based on continuous operation, for 8 hours or less operation; the decrease in plant capital costs would not be significant.

3.2 Life Cycle Cost (1977 Dollars)

The life cycle cost (LCC) formula applicable to this system is:

LCC = AC + FC + OMC

where AC = Acquisition Cost (See Section 3.1)

FC = Total Fuel Cost over System Lifetime (see Section 3.6)

OMC = Operation and Maintenance Cost over System Lifetime (See Section 3.15)

A. Oil Fired Plant

Requirement	LCC (1977)	LCC/yr (1977)
50 Mw Cont.	724,520,000	18,100,000
1 hr.	66,900,000	1,672,000
10 Mw Cont.	198,939,000	4,970,000
8 hr.	75,930,000	1,800,000
1 hr.	23,190,000	580,000

B. Natural Gas Fired Plant

Requirement	LCC (1977)	LCC/yr (1977)
50 Mw Cont.	368,400,000	9,200,000
1 hr.	52,100,000	1,300,000
10 Mw Cont.	108,330,000	2,700,000
8 hr.	42,130,000	1,053,000
1 hr.	19,410,000	485,000

3.3 Lifetime (Years)

Requirement	1977
50 Mw Cont.	40
1 hr.	40
10 Mw Cont.	40
8 hr.	40
1 hr	40

3.4 Volume/Size

Requirement	Approximate Land Area Required	
	sq. ft.	sq. m.
50 Mw Cont.	100,000	9,200
1 hr.	100,000	9,200
10 Mw Cont.	50,000	4,600
8 hr.	50,000	4,600
1 hr.	50,000	4,600

3.5 Weight

Weight is not a relevant parameter for this type of system. Plant cannot be air lifted to provide ground power to remote site. Plant must be constructed at a fixed site.

3.6 Fuel

A. No. 2 Fuel Oil

Requirement	Amount Per Year tons	Amount Per Year kg	Average Cost Per Year (1977 Dollars)	Time Between Deliveries
50 Mw Cont.	97,300	88,150,000	16,640,000	2 weeks
1 hr.	4,050	3,680,000	700,000	2 weeks
10 Mw Cont.	24,800	22,518,000	4,235,000	2 weeks
8 hr.	11,800	10,700,000	1,410,000	2 weeks
1 hr.	1,000	908,000	176,500	2 weeks

B. Natural Gas

Requirement	Amount Per Year Cubic Feet	Average Cost Per Year (1977 Dollars)	Time Between Deliveries
50 Mw Cont.	3.74×10^9	7,740,000	--
1 hr.	$.15 \times 10^9$	325,600	--
10 Mw Cont.	$.951 \times 10^9$	1,960,000	--
8 hr.	$.452 \times 10^9$	656,000	--
1 hr	$.04 \times 10^9$	82,000	--

Continuous delivery of natural gas assumed through pipeline. Storage facilities for surges provided.

C. <u>Alternate Fuels</u>

Power Plant can be adapted to the use of other distillate fuels including those derived from coal.

D. <u>Fuel Availability</u>

The availability of distillate fuels derived from crude oil and natural gas beyond the year 2000 is uncertain.

Beyond that period, these types of power plants may have to operate on coal derived fuels.

3.7 Environmental Constraints

The environmental constraints of the power system are indicated in the following tabulation:

X amount of uncontrolled emission

Y Amount of pollution which would be emitted with no controls

Z Degree of difficulty in meeting more strict regulations

Key: blank - none

0 - minor

◐ - moderate

● - major

Emissions	X	Y	Z
Thermal Discharge (a)	◐	-	-
Thermal Discharge (b)	●	●	●
Air Pollution			
CO	0	-	0
HC	0	-	0
NO_x	◐	-	◐
SO_x	◐	-	●
Particulates	◐	0	◐
Noise	◐	◐	◐
Solid Waste	◐	-	●
Chemical Waste	0	-	0
Radioactive Waste	-	-	-

Notes: (a) system is air or water cooled; heat rejected directly to atmosphere.
(b) system is water cooled; heat rejected to body of water or cooling tower. Water source and/or make-up required.

3.8 Location Constraints

The locational limitations of the power system, and the degree of difficulty in overcoming these limitations are indicated in the following tabulation.

— - no difficulty

O - minor difficulty

◐ - major difficulty

● - overriding limitation

LOCATION RESTRAINT	
Water required for cooling	◐
Water required for process	◐
Manning required during operation	●
Fuel deliveries required	●
Adequate solar insolation required	-
Adequate wind speed required	-
Isolation from population required	-
Electricity required for charging	-

3.9 Operational Constraints

The tabulated operating characteristics are applicable to the power system as indicated.

— - Characteristic not observed in system operation

O - Characteristic has minor effect on system performance

◓ - Characteristic has moderate effect on system performance

● - Characteristic has major effect on system performance

Operational Restraint	
Efficiency reduction at part load	◓
Part load capability limitation	◓
Dependence on solar insolation	–
Dependence on wind consistency	–
Overload capacity limitations	◓
Delayed response to rapid load changes	◓
Life reduction from frequent rapid load changes	◓

3.10 System Efficiency

Requirement	1977
50 Mw Cont.	28%
1 hr.	28%
10 Mw Cont.	22%
8 hr.	22%
1 hr.	22%

3.11 Type of System

Requirement	Mobile	Trans-portable	Fixed	Construction Time (years)
50 Mw Cont.			X	3
1 hr.			X	3
10 Mw Cont.			X	3
8 hr.			X	3
1 hr.			X	3

3.12 Start-up/Shutdown Times

Requirement	Start-up *	Shut-down
50 Mw Cont.	8 hr.	8 hr.
1 hr.	8 hr.	8 hr.
10 Mw Cont.	8 hr.	8 hr.
8 hr.	8 hr.	8 hr.
1 hr.	8 hr.	8 hr.

*Assuming cold start.

3.13 Growth Potential

This type of power plant is non-modular by nature with the result that growth in capacity can be achieved only be adding on additional boiler and turbine. If growth is planned from the beginning, equipment can be oversized for future additional capacity.

3.14 Reliability

The tabulated conditions exist in the power system to the extent indicated.

— - Condition does not exist in system

O - Condition exists, but its extent is sufficiently minor as to have minimal effect on system performance or reliability

◐ - Condition exists, and its extent is sufficient to have a moderate effect on system performance or reliability

● - Condition exists and is a governing factor in determining system performance and reliability.

Conditions	
Numerous moving parts	●
High temperature operation	O
High stress levels	O
High radiation level	-
Corrosive attack	O
Thermal cycling	◐
Non-modular design	●
Solar insolation required	-
Wind required	-

3.15 Maintenance and Operation

Requirement	Cost Per Year	Overhaul Duration (wks/yr)	Personnel Required Continuously
50 Mw Cont.	735,000	4	Yes
1 hr.	245,000	2	No
10 Mw Cont.	500,000	4	Yes
8 hr.	165,000	2	No
1 hr.	165,000	2	No

Operation and Maintenance Requirements

An operating crew must be in constant attendence during operation of the power plant. A maintenance team must be available at the site to perform routine power plant maintenance. The maintenance crew would consist of machinists, instrument technicians, electricians, welders, etc.

3.16 Other Energy Production

Requirements	10^6 Btu/hr	10^3 kw Thermal
50 Mw Cont.	263	77.1
1 hr.	263	77.1
10 Mw Cont.	72.6	21.3
8 hr.	72.6	21.3
1 hr.	72.6	21.3

For a power plant of this type, thermal energy is normally discharged to the environment in two forms: (a) low temperature condenser heat rejection to a body of water or to the atmosphere via wet or dry cooling towers and (b) boiler exhaust gases at high temperatures directly to the atmosphere via a chimney. The electrical power output of the plant is maximized by making the temperatures of the thermal discharges as low as practicable. To utilize the exhaust gases for heating purposes, the gases can be diverted to the areas requiring heat with the use of an intermediate heat exchanger. The exhaust gases leaving the stack can provide approximately 10 percent of the boiler thermal output for other uses. Temperatures are suitable for the production of saturated or super-heated steam.

3.17 Availability of Raw Building Materials

Raw building materials are readily availability for this type of power plant.

3.18 Development

No development costs are necessary for this type of power plant as all the equipment utilized is commercially available.

No risk is involved as proven technology is utilized in the design and construction of this plant.

4.0 REFERENCES

(1) Types and Characteristics of Industrial Duel Purpose Power Plants, FEA Contract CRO-4-60712-00, by Burns and Roe, dated January 4, 1976.

(2) ERDA 76-141, Comparing New Technologies for the Electric Utilities, dated 12/9/76, Draft Final Report.

(3) Report on Equipment Availability for the Thirteen-Year Period, 1960-1972, EEI Publication No. 73-46, issued December, 1973.

SECTION X

STIRLING ENGINE GENERATOR (CHEMICAL FUEL)

1.0 SYSTEM DESCRIPTION

1.1 System Identification

Fuel Converter - furnace

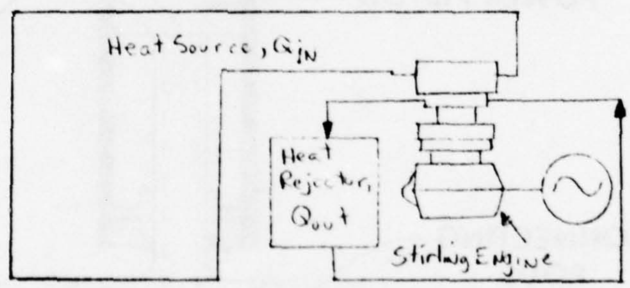
Energy Converter/Cycle - stirling engine generator set/ stirling cycle

Fuel - No. 2 distillate oil

Working Fluid - helium

Equivalent Alternate Types - none

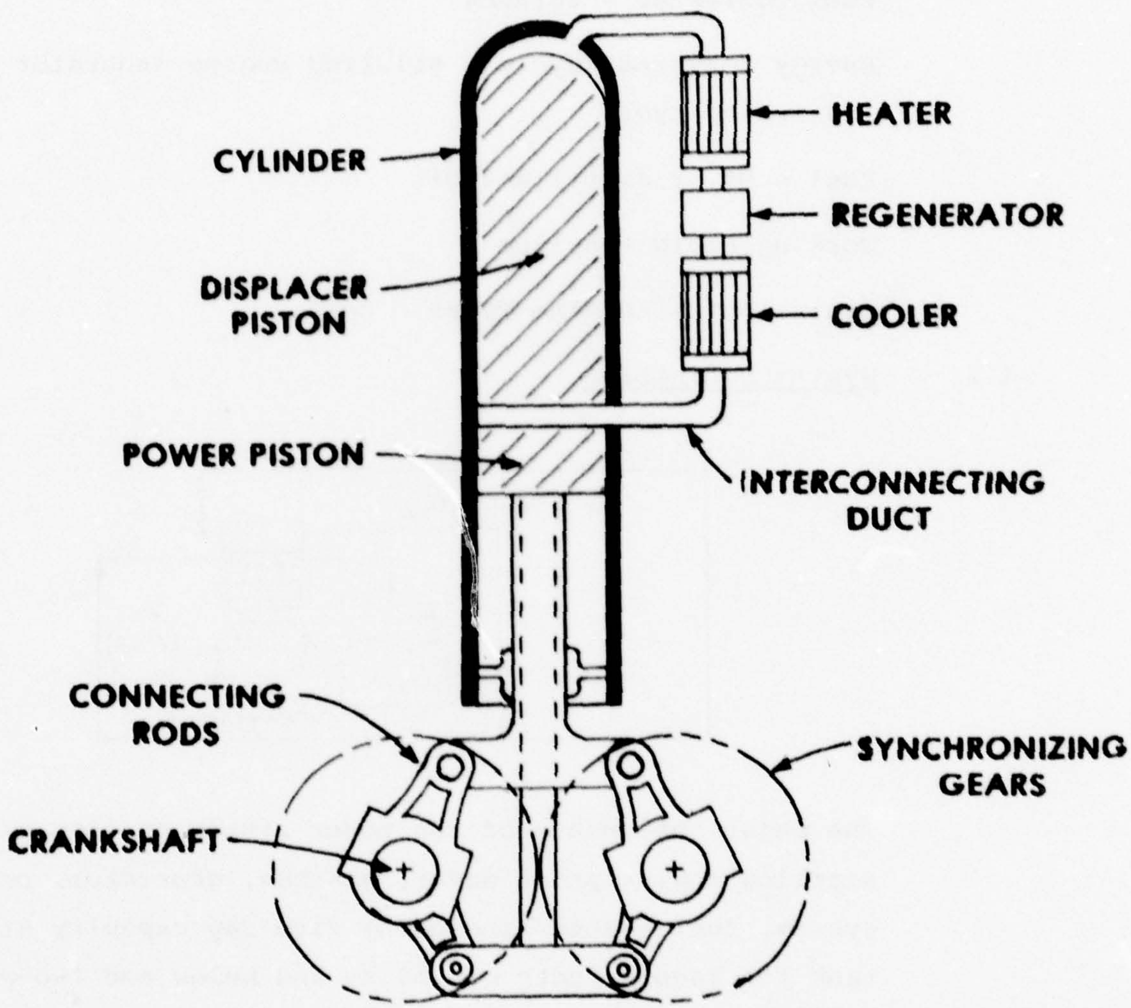
1.2 System Definition



The major components of the power system consist of the stirling engine prime mover, gearbox, generator, control system, fuel system (including five-day capacity storage tank for requirements of 750 kw and below and two-week capacity storage tank for larger requirements), intake plenum, air filter, exhaust ducting, and exhaust plenum for the burner, heat exchanger and pump for the cooler. Foundations and housings are included for the 10 Mw systems.

1.3 PHYSICAL DESCRIPTION

STIRLING CYCLE



RHOMBIC DRIVE CRANK MECHANISM

2.0 LIST OF REQUIREMENTS AND TIME FRAMES

This power system is applicable to the following electrical power requirements as marked. The first date listed indicates the earliest time when the system will be available for purchase. Later dates indicate the point in time when significant improvements are expected.

	ELECTRICAL POWER REQUIREMENTS	1985
50 Mw	Continuous (60 Hz - 3 ø - 13.8 kV)	N/A
	1-hour (60 Hz - 3 ø - 13.8 kV)	N/A
10 MW	Continuous (60 Hz - 3 ø - 4160 V)	X
	8 - hour (60 Hz - 3 ø - 4160 V)	X
	1 - hour (60 Hz - 3 ø - 4160 V)	X
750 kw	Continuous (60 Hz - 3 ø - 4160 V)	X
250 kw	Continuous (60 Hz - 3 ø - 480 V)	X
50 kw	Continuous (60 Hz - 3 ø - 480 V)	X
	8 - hour (60 Hz - 3 ø - 480 V)	X
	1 - hour (60 Hz - 3 ø - 480 V)	X
10 kw	Continuous #1 (DC - 28 V)	X
	Continuous #2 (60 Hz - 3 ø - 240 V)	X
	Continuous #3 (60 Hz - 1 ø - 240 V)	X
	Continuous #4 (60 Hz - 1 ø - 120 V)	X
	8 - hour #1 (DC - 28 V)	X
	8 - hour #2 (60 Hz - 3 ø - 240 V)	X
	1 - hour (60 Hz - 3 ø - 240 V)	X

* For this study, the optimum, maximum projected engine size is 1,000 kw. Common practice would preclude operating more than ten engines in parallel to meet the 50 Mw requirements.

3.0 PARAMETERS

3.1 Acquisition Cost (1977 Dollars)

The costs listed below are for a complete Stirling Engine Generator System including engine, generator, heat source, heat rejector and foundations and housings for the 10 Mw requirements only.

Requirements	1985
10 Mw Cont.	2,581,000
8 hr.	2,457,000
1 hr.	2,457,000
750 kw Cont.	180,000
250 kw Cont.	64,900
50 kw Cont.	22,100
8 hr.	19,000
1 hr.	19,000
10 kw Cont. #1, 2, 3, 4	6,770
8 hr. #1, 2	6,270
1 hr	6,270

3.2 Life Cycle Cost (1977 Dollars)

The life cycle cost is defined by the following equation:

LCC = AC + FC + OMC

where AC = Acquisition Cost (See Section 3.1)

FC = Total Fuel Cost Over System Lifetime (See Section 3.6)

OMC = Operation and Maintenance Cost Over System Lifetime (See Section 3.15)

Requirements	LCC 10^3 1977\$ 1985	LCC/YR 10^3 1977\$ 1985
10 Mw Cont.	54,750	2,190
8 hr.	27,420	1,097
1 hr.	5,578	223
750 kw Cont.	4,090	164
250 kw Cont.	1,400	56
50 kw Cont.	323	12.9
8 hr.	172	6.87
1 hr.	38.2	1.53
10 kw Cont. #1, 2, 3, 4	95.3	3.81
8 hr. #1, 2	56.7	2.27
1 hr.	12.5	.50

3.3 Lifetime (years)

Requirement	Lifetime (years)
All	25

3.4 Volume/Size

The volume occupied by the power system is indicated in the following table. The physical proportions can be determined from Section 1.3.

Requirements	Volume ft^3	Volume m^3
10 Mw Cont., 8 hr., 1 hr.	10,070*	285*
750 kw Cont.	600	17
250 kw Cont.	200	5.7
50 kw Cont., 8 hr., 1 hr.	79	2.2
10 kw Cont. #1, 2, 3, 4	24	0.67
8 hr. #1, 2, 1 hr.	24	0.67

* 10 Mw requirement consists of ten 1000 kw units operating in parallel.

3.5 <u>Weight</u>

The weight of the power system is indicated in the following tabulation.

Requirement	System Weight		Module Weight	
	lb	Kg	lb	Kg
10 Mw Cont., 8 hr., 1 hr.	250,000*	113,400*	25,000	11,340
750 kw Cont.	14,250	6,460	NA	
250 kw Cont.	5,380	2,440	NA	
50 kw Cont., 8 hr., 1 hr.	1,840	834	NA	
10 kw Cont. #1, 2, 3, 4	470	213	NA	
8 hr. #1, 2, 1 hr.	470	213	NA	

* The ten Mw requirement consists of ten 1,000 kw units operating in parallel.

3.6 Fuel

The cost of No. 2 fuel and the quantity consumed by the power system is indicated in the following tabulation.

Requirements	Amount Per Year 10^3 gal	Amount Per Year 10^3 Kg	Average Cost Per Year* 10^3 1977 $	Time Between Deliveries
10 Mw Cont.	3,298	10,780	2,012	2 weeks
10 Mw 8 hr.	1,570	5,132	958	2 weeks
10 Mw 1 hr.	196	641	120	2 weeks
750 kw Cont.	276	902	151	5 days
250 kw Cont.	92	301	50.3	5 days
50 kw Cont.	16.5	53.9	10.1	5 days
50 kw 8 hr.	7.9	25.8	4.79	5 days
50 kw 1 hr.	0.98	3.20	.60	5 days
10 kw Cont. #1, 2, 3, 4	3.30	10.79	2.01	5 days
10 kw 8 hr. #1, 2	1.57	5.13	.96	5 days
10 kw 1 hr.	.20	.65	.12	5 days

* Cost per year is calculated by dividing the cost of fuel over the life of the system by the life in years. The system life is given in Section 3.3. All systems begin operation in 1985, and fuel costs are escalated by the method given in Appendix A.

3.7 Environmental Constraints

The environmental constraints of the power system are indicated in the following tabulation:

X amount of uncontrolled emission

Y Amount of pollution which would be emitted with no controls

Z Degree of difficulty in meeting more strict regulations

Key: blank - none

0 - minor

◐ - moderate

● - major

Emissions	X	Y	Z
Thermal Discharge (a)	●	-	-
Thermal Discharge (b)	-	-	-
Air Pollution			
CO	0	-	0
HC	0	-	0
NO_x	◐	-	◐
SO_x	◐	-	◐
Particulates	0	0	◐
Noise	◐	◐	◐
Solid Waste	-	-	-
Chemical Waste	-	-	-
Radioactive Waste	-	-	-

Notes: (a) system is air or water cooled; heat rejected directly to atmosphere.

(b) system is water cooled; heat rejected to body of water or cooling tower. Water source and/or make-up required.

3.8 Location Constraints

The locational limitations of the power system, and the degree of difficulty in overcoming these limitations are indicated in the following tabulation.

— - no difficulty
O - minor difficulty
◐ - major difficulty
● - overriding limitation

LOCATION RESTRAINT	
Water required for cooling	-
Water required for process	-
Manning required during operation	O
Fuel deliveries required	●
Adequate solar insolation required	-
Adequate wind speed required	-
Isolation from population required	-
Electricity required for charging	-

3.9 Operational Constraints

The tabulated operating characteristics are applicable to the power system as indicated.

- – Characteristic not observed in system operation
- O – Characteristic has minor effect on system performance
- ◐ – Characteristic has moderate effect on system performance
- ● – Characteristic has major effect on system performance

Operational Restraint	
Efficiency reduction at part load	O
Part load capability limitation	O
Dependence on solar insolation	–
Dependence on wind consistency	–
Overload capacity limitations	O
Delayed response to rapid load changes	O
Life reduction from frequent rapid load changes	O

3.10 System Efficiency

The power system efficiency is indicated in the following tabulation.

Requirement	Efficiency %
All	45

3.11 Type of System

The system type is indicated in the following tabulation.

M - mobile

T - transportable

F - fixed

Time - time necessary for assembly or construction

Requirement	M	T	F	Time
10 Mw Cont., 8 hr., 1 hr.		X		8 hrs.
750 kw Cont.	X			
250 kw Cont., 8 hr., 1 hr.	X			
10 kw Cont. #1, 2, 3, 4	X			
8 hr. #1, 2, 1 hr.	X			

3.12 Start-up/Shutdown Times

The startup and shutdown time for the power system is indicated in the following tabulation.

Requirement	Start-up	Shutdown
10 Mw Cont., 8 hr., 1 hr.	60 sec.	60 sec.
750 kw Cont.	60 sec.	60 sec.
250 kw Cont.	60 sec.	60 sec.
50 kw Cont., 8 hr., 1 hr.	60 sec.	60 sec.
10 kw Cont. #1, 2, 3, 4,	60 sec.	60 sec.
8 hr. #1, 2, 1 hr.	60 sec.	60 sec.

3.13 Growth Potential

The power system is not modular in construction (except for the 10 Mw case which utilizes multiple units operating in parallel). As a result, incremental increases in output cannot be achieved without duplicating the original system (except for the 10 Mw case).

3.14 Reliability

The tabulated conditions exist in the power system to the extent indicated.

— - Condition does not exist in system

O - Condition exists, but its extent is sufficiently minor as to have minimal effect on system performance or reliability

◐ - Condition exists, and its extent is sufficient to have a moderate effect on system performance or reliability

● - Condition exists and is a governing factor in determining system performance and reliability.

Conditions	
Numerous moving parts	O
High temperature operation	O
High stress levels	O
High radiation level	-
Corrosive attack	O
Thermal cycling	O
Non-modular design	●
Solar insolation required	-
Wind required	-

3.15 Maintenance and Operation

The annual maintenance and operating costs for the power system are listed in the following tabulation.

Requirement	Operation and Maintenance 1977 $/yr	Personnel Required Continuously
10 Mw Cont.	74,780	No
8 hr.	40,280	No
1 hr.	5,070	No
750 kw Cont.	5,475	No
250 kw Cont.	3,094	No
50 kw Cont.	1,976	No
8 hr.	1,313	No
1 hr.	165	No
10 kw Cont. #1, 2, 3, 4	1,530	No
8 hr. #1, 2	1,058	No
1 hr.	138	No

3.16 Other Energy Production

Thermal energy can be recovered from the engine jacket cooling water and from the burner exhaust. The temperature of the engine jacket is suitable for the production of hot water, while the exhaust temperature is suitable for the production of saturated or superheated steam.

Requirement	10^6 Btu/hr	10^3 kw Thermal
10 Mw Cont., 8 hr. 1 hr.	25.0	7.33
750 kw Cont.	1.88	0.55
250 kw Cont.	0.63	0.18
50 kw Cont., 8 hr., 1 hr.	0.13	0.037
10 kw Cont., #1, 2, 3, 4,	0.025	0.007
8 hr. #1, 2, 1 hr.	0.025	0.007

3.17 Availability of Raw Building Materials

No critically short materials are required for the power system.

3.18 Development

The following organizations are involved in stirling engine research:

Organization	Location
United Stirling	Malmer, Sweden
Philips Labs	Briarcliff Manor, NY
Ford Motor Company	Dearborn, MI
NASA	
Energy Research & Generation, Inc.	Oakland, CA
Mechanical Technology, Inc.	Latham, NY

4.0 REFERENCES

1. D. Lehrfeld, "Practicability Study of Stirling Total Energy Systems", 12th IECEC 1977, 779251.

SECTION XI

MHD GENERATOR (CHEMICAL FUEL)

1.0 SYSTEM DESCRIPTION

1.1 System Identification

Energy Converter/Cycle: Fossil fueled combustor/open cycle MHD unit: (1) combined with Rankine cycle steam bottoming unit for 50 MW continuous power requirements and (2) without steam bottoming unit for all 50 Mw and 10 Mw power requirements.

Fuel: Pulverized coal (either high or low sulfur content)

Working Fluid: High temperature combustion gas, partially ionized with recoverable seeding material, e.g., potassium.

Equivalent Alternate Type: Fuel oil-fired MHD unit.

1.2 System Definition

MHD (magnetohydrodynamic) power generation utilizes the movement of electrically conducting gas through a magnetic field. In an MHD generator, hot, partially ionized compressed gas is expanded in a duct and forced through a strong magnetic field. Electrodes in the sides of the duct pick up the potential (voltage) generated in the gas, so that current flows through the circuit of gas, electrodes, and external load. Ionization of the combustion gas is increased by the addition of a seeding material such as potassium, introduced as potassium carbonate. For continuous operation, a high percentage of the seed material must be recovered and recycled in order to avoid excessive economic penalties to the system. The exhaust gas from an MHD generator is passed in turn through an air preheater and, for selected power requirements, through steam bottoming plant boiler components.

A 50 Mw open cycle MHD plant with a steam bottoming cycle consists of the following major components:

Coal Processing and Injector Equipment
Combustor/Nozzle
MHD Generator/Diffuser
MHD Generator (spare)
Magnet/Dewar (superconducting)
High Temperature Air Heater
Low Temperature Air Heater
Steam Turbine/Compressor
Seed Handling and Injection Equipment
Seed Recovery and Reprocessing Equipment

Electrostatic Precipitators

Radiant Furnace

Secondary Furnace - SH/RH

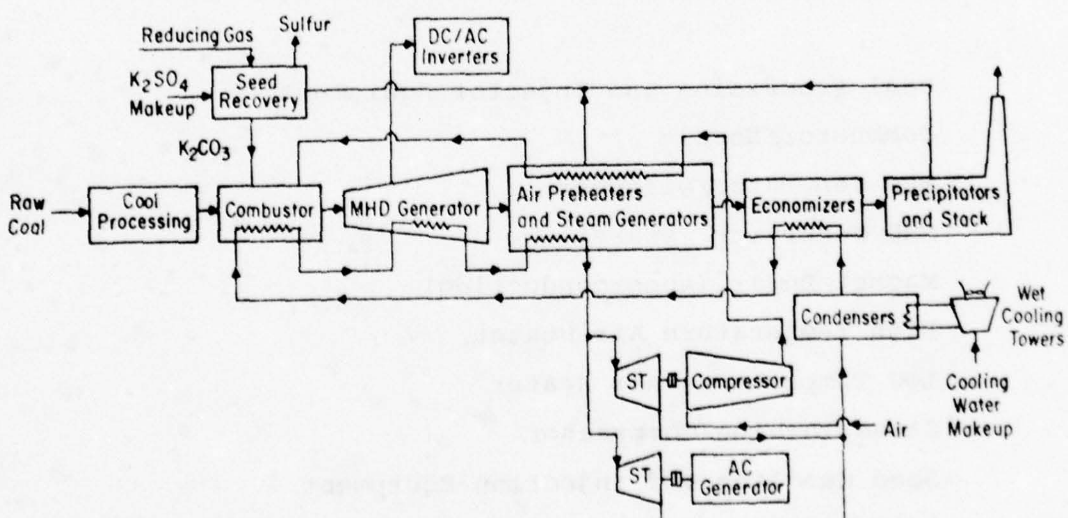
Economizers

Steam Turbine/Generator

Inversion Equipment

An MHD plant without steam bottoming would consist of the same components as outlined above, but without the radiant furnace, economizers, and steam turbine/generator. Also the steam turbine/compressor may be replaced by: a gas turbine driven compressor, or by a pressurized oxygen/nitrogen supply system, in which case the high temperature air heater may be eliminated.

The advantage of an MHD generator with steam bottoming is the higher efficiency attainable compared to a unit without steam bottoming. An advantage of an MHD unit without steam bottoming is rapid start-up capability, with times as low as one second to produce full power.

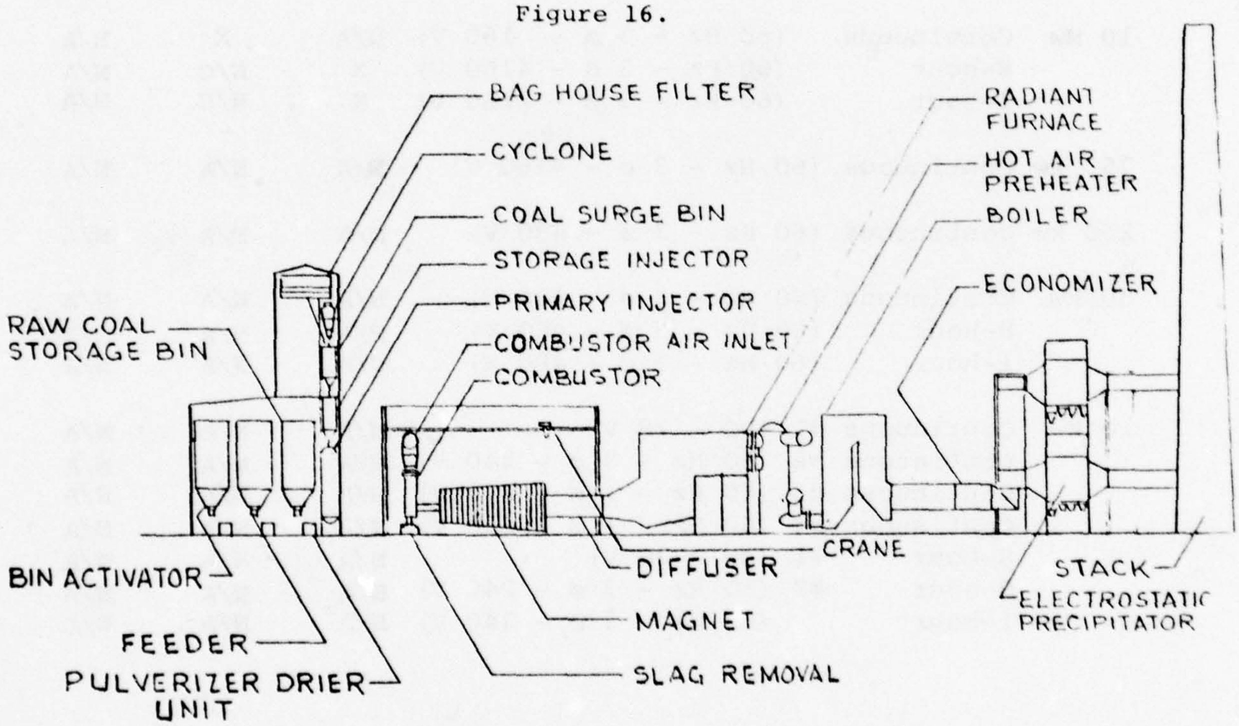


Simplified Schematic Diagram of Open Cycle MHD

1.3 Physical Description

An elevation (view) through the combustion gas flow path of a proposed open cycle MHD plant with a steam bottoming cycle follows. For a 50 Mw MHD plant, the overall plan dimensions of the main plant island are approximately 200' (length as shown below) x 100' (width).

Figure 16.



ELEVATION OF MAIN PLANT ISLAND THROUGH COMBUSTION GAS FLOW PATH

2.0 LIST OF REQUIREMENTS AND TIME FRAMES

This power system is applicable to the following electrical power requirements as marked. The first date listed indicates the earliest time when the system will be available for purchase.

ELECTRICAL POWER REQUIREMENTS			Without Steam Bottoming Unit 1985	Without Steam Bottoming Unit 1990	With Steam Bottoming Unit 1990
50 Mw	Continuous	(60 Hz - 3 ø - 13.8 kV)	N/A*	X	X
	1-hour	(60 Hz - 3 ø - 13.8 kV)	X	N/C**	N/A
10 Mw	Continuous	(60 Hz - 3 ø - 160 V)	N/A	X	N/A
	8-hour	(60 Hz - 3 ø - 4160 V)	X	N/C	N/A
	1-hour	(60 Hz - 3 ø - 4160 V)	X	N/C	N/A
750 kw	Continuous	(60 Hz - 3 ø - 4160 V)	N/A	N/A	N/A
250 kw	Continuous	(60 Hz - 3 ø - 480 V)	N/A	N/A	N/A
50 kw	Continuous	(60 Hz - 3 ø - 480 V)	N/A	N/A	N/A
	8-hour	(60 Hz - 3 ø - 480 V)	N/A	N/A	N/A
	1-hour	(60 Hz - 3 ø - 480 V)	N/A	N/A	N/A
10 kw	Continuous #1	(DC - 28 V)	N/A	N/A	N/A
	Continuous #2	(60 Hz - 3 ø - 240 V)	N/A	N/A	N/A
	Continuous #3	(60 Hz - 1 ø - 240 V)	N/A	N/A	N/A
	Continuous #4	(60 Hz - 1 ø - 120 V)	N/A	N/A	N/A
	8-hour #1	(DC - 28 V)	N/A	N/A	N/A
	8-hour #2	(60 Hz - 3 ø - 240 V)	N/A	N/A	N/A
	1-hour	(60 Hz - 3 ø - 240 V)	N/A	N/A	N/A

*N/A - Power systems for 10 to 750 kw were not listed. The open cycle MHD generator system is inefficient in these lower sizes, whereas it becomes very efficient in the larger power station sizes, e.g., over 600 Mw. In addition, continuous duty operation is not expected to be reliable until 1990.

**N/C - No change from the 1985 cases.

3.0 PARAMETERS

3.1 Acquisition Cost (1977 Dollars)

Requirement	Without Steam Bottoming		With Steam Bottoming
	1985	1990	1990
50 Mw Cont.	-	112,000,000	92,000,000
1 hr.	101,000,000	-	-
10 Mw Cont.	-	44,000,000	-
8 hr.	42,000,000	-	-
1 hr.	40,000,000	-	-

It should be noted from the above table that for the 50 Mw plant the acquisition cost is lower for the unit with the steam bottoming plant. This results from the significantly higher efficiency of the MHD unit when combined with the steam plant, which greatly reduces thermal input, and therefore the size of certain components of the plant.

3.2 Life Cycle Cost (1977 Dollars)

The life cycle cost is defined by the following equation:

$$LCC = AC + FC + OMC$$

where AC = Acquisition Cost (see Section 3.1)

FC = Total Fuel Cost Over System Lifetime (see Section 3.6)

OMC = Operation and Maintenance Cost Over System Lifetime (see Section 3.15)

	LCC 10^3 1977 $			LCC/YR 10^3 1977 $		
	Without Steam Bottoming		With Steam Bottoming	Without Steam Bottoming		With Steam Bottoming
Requirement	1985	1990	1990	1985	1990	1990
50 Mw Cont.	-	375,000	256,000		12,500	8,530
1 hr.	128,000	-	-	4,270	-	-
10 Mw Cont.	-	116,000	-	-	3,870	-
8 hr.	76,000	-	-	2,530	-	-
1 hr.	48,200	-	-	1,600	-	-

3.3 Lifetime (years)

The useful service life of the power system is indicated in the following table.

Requirement	1985, 90
50 Mw Cont.	30 *
1 hr.	30
10 Mw Cont.	30
8 hr.	30
1 hr.	30

*MHD generator channel replaced periodically

3.4 Volume/Size

The space occupied by the power system is indicated in the following table.

Requirement	Land Area Acres	Land Area ft^2	Land Area m^2
50 Mw Cont. with steam bottoming	76	3,300,000	310,000
50 Mw Cont. without steam bottoming	121	5,300,000	490,000
50 Mw 1 hr.	25.0	1,100,000	100,000
10 Mw Cont.	33.7	1,500,000	140,000
10 Mw 8 hr.	19.4	850,000	79,000
10 Mw 1 hr.	9.7	420,000	39,000

3.5 Weight

Weight is not a relevant parameter for this type of system. Plant cannot be air lifted to provide ground power to remote sites. Plant must be constructed at a fixed site.

3.6 Fuel

The amount of fuel (coal) consumed per year (lb and kg) and the average cost per year, and the time between deliveries is indicated in the following tabulation.

Requirement	Amount Per Year — Without Steam Bottoming 1985 lb	Without Steam Bottoming 1985 kg	Without Steam Bottoming 1990 lb	Without Steam Bottoming 1990 kg	With Steam Bottoming 1990 lb	With Steam Bottoming 1990 kg	Average Cost Per Year 10^3 $ (1977) — Without Steam Bottoming 1985	Without Steam Bottoming 1990	With Steam Bottoming 1990	Time* Between Deliveries
50 Mw Cont.	-	-	$484x10^6$	$220x10^6$	294	134	-	6,582	4,000	3 Months
50 Mw 1 hr.	$28.8x10^6$	$13.1x10^6$	-	-	-	-	370	-	-	3 Months
10 Mw Cont.	-	-	$121x10^6$	$55x10^6$	-	-	-	1,646	-	3 Months
10 Mw 8 hr.	$26.2x10^6$	$26.2x10^6$	-	-	-	-	740	-	-	3 Months
10 Mw 1 hr.	$3.3x10^6$	$3.3x10^6$	-	-	-	-	93	-	-	3 Months

*The time between deliveries is based on typical total accumulated storage that could be drawn upon in the event of unusual coal delivery stoppage. Usual coal delivery may be more often - e.g., weekly - to suit convenience of operations.

Alternate Fuels

High Sulfur Coal: Fuel cost is slightly lower than low sulfur coal, however, acquisition cost of the plant is higher due to necessity for additional air pollution control equipment required to meet environmental regulations for sulfur oxide emissions.

Residual Fuel Oil: Residual fuel oil is an alternate fuel, however, present emphasis is on development of coal fired MHD plants.

Fuel Availability

Fuel availability is not a problem. Adequate coal supplies are available in the United States.

3.7 Environmental Constraints

The environmental constraints of the power system are indicated in the following tabulation:

X amount of uncontrolled emission

Y Amount of pollution which would be emitted with no controls

Z Degree of difficulty in meeting more strict regulations

Key: blank - none

0 - minor

◐ - moderate

● - major

Emissions	X	Y	Z
Thermal Discharge (a)	◐	-	-
Thermal Discharge (b)	●	●	●
Air Pollution			
CO	0	-	0
HC	0	-	0
NO_x	◐	-	●
SO_x	◐	-	◐
Particulates	●	●	●
Noise	0	0	0
Solid Waste	●	-	●
Chemical Waste	0	-	0
Radioactive Waste	-	-	-

Notes: (a) system is air or water cooled; heat rejected directly to atmosphere.
(b) system is water cooled; heat rejected to body of water or cooling tower. Water source and/or make-up required.

3.8 Location Constraints

The locational limitations of the power system, and the degree of difficulty in overcoming these limitations are indicated in the following tabulation.

— - no difficulty

O - minor difficulty

◐ - major difficulty

● - overriding limitation

LOCATION RESTRAINT	
Water required for cooling	◐
Water required for process	◐
Manning required during operation	●
Fuel deliveries required	●
Adequate solar insolation required	-
Adequate wind speed required	-
Isolation from population required	-
Electricity required for charging	-

3.9 Operational Constraints

The tabulated operating characteristics are applicable to the power system as indicated.

— - Characteristic not observed in system operation

O - Characteristic has minor effect on system performance

◐ - Characteristic has moderate effect on system performance

● - Characteristic has major effect on system performance

Operational Restraint	
Efficiency reduction at part load	◐
Part load capability limitation	◐
Dependence on solar insolation	-
Dependence on wind consistency	-
Overload capacity limitations	◐
Delayed response to rapid load changes	◐
Life reduction from frequent rapid load changes	◐

3.10 System Efficiency

The power system efficiency is indicated in the following tabulation.

Requirement	Efficiency, % Without Steam Bottoming 1985	Without Steam Bottoming 1990	With Steam Bottoming 1990
50 Mw Cont.	-	20	33
50 Mw 1 hr.	20	-	-
10 Mw Cont.	-	16	-
10 Mw 8 hr.	16	-	-
10 Mw 1 hr.	16	-	-

3.11 Type of System

The system type is indicated in the following tabulation.

M - mobile

T - transportable

F - fixed

Time - time for assembly or construction

Requirement	M	T	F	Time
50 Mw Cont.			X	5 years
50 Mw 1 hr.			X	5 years
10 Mw Cont.			X	4 years
10 Mw 8 hr.			X	4 years
10 Mw 1 hr.			X	4 years

3.12 Start-up/Shut-down Times

The order of magnitude of start-up and shut-down times for the power system is indicated in the following tabulation. Preheating of certain systems is assumed, and the times for the requirements without steam bottoming are for oxygen enriched systems.

Requirement	Without Steam Bottoming 1985	Without Steam Bottoming 1990	With Steam Bottoming 1990
50 Mw Cont.	-	1 second	1 hour
50 Mw 1 hr.	1 second	-	-
10 Mw Cont.	-	1 second	-
10 Mw 8 hr.	1 second	-	-
10 Mw 1 hr.	1 second	-	-

3.13 Growth Potential

The power system is non-modular by nature with the result that growth in capacity can be achieved only by adding an additional complete unit.

3.14 Reliability

The tabulated conditions exist in the power system to the extent indicated.

- \- Condition does not exist in system

O - Condition exists, but its extent is sufficiently minor as to have minimal effect on system performance or reliability

◐ - Condition exists, and its extent is sufficient to have a moderate effect on system performance or reliability

● - Condition exists and is a governing factor in determining system performance and reliability.

Conditions	
Numerous moving parts	●
High temperature operation	●
High stress levels	O
High radiation level	-
Corrosive attack	●
Thermal cycling	◐
Non-modular design	●
Solar insolation required	-
Wind required	-

3.15 Maintenance and Operation

The annual maintenance and operating costs for the power system are listed in the following tabulation.

Requirement	Operation and Maintenance 1977 $/yr			Personnel Required Continuously
	Without Steam Bottoming		With Steam Bottoming	
	1985	1990	1990	
50 Mw Cont.	-	2,195,000	1,466,000	Yes
50 Mw 1 hr.	535,580	-	-	Yes
10 Mw Cont.	-	724,000	-	Yes
10 Mw 8 hr.	400,000	-	-	Yes
10 Mw 1 hr.	177,000	-	-	Yes

It should be noted that a more than proportionate amount of operation and maintenance time is required for less than continuous operation. This results primarily from necessary preparation of systems prior to start-up and securing of systems after shutdown.

3.16 Other Energy Production

Thermal energy is recovered in the 50 Mw continuous operating open cycle MHD plant by utilization of a steam bottoming unit. The use of an MHD generator for short duration power requirements does not lend itself to utilizing thermal energy for other energy production.

In general, the electrical power output of the MHD plant is maximized by making the temperatures of the thermal discharges as low as possible. Heat is rejected from the steam bottoming cycle at temperatures so low as to be appropriate for the production of low temperature hot water at best.

Requirement	Without Steam Bottoming				With Steam Bottoming	
	1985		1990		1990	
	Btu/hr	Mw Thermal	Btu/hr	Mw Thermal	Btu/hr	Mw Thermal
50 Mw Cont.	-	-	410×10^6	120	210×10^6	60.9
50 Mw 1 hr.	410×10^6	-	-	-	-	-
10 Mw Cont.	-	-	110×10^6	31.5	-	-
10 Mw 8 hr.	110×10^6	31.5	-	-	-	-
10 Mw 1 hr.	110×10^6	31.5	-	-	-	-

3.17 Availability of Raw Building Materials

Raw building materials are readily available for this type of power plant.

3.18 Development

Among achievements to date, 32 Mw have been generated for approximately one minute using a liquid fuel fired combustor, and 20 Mw have been generated for thirty minutes using natural gas combustion - in the United States and Soviet Union, respectively. Additional testing using pulverized coal has been performed at lower power levels.

Additional development effort is required to advance MHD technology from its current state to prototypes indicated in the list of requirements.

At present, there is a U.S. development program geared towards the development of a 1000 Mw open cycle MHD base load plant with steam bottoming. The overall cost of the development program through the first year of operation of a demonstration plant is estimated at approximately \$1.2 billion. The overall cost of the development program through the first year of operation of a demonstration plant is estimated at approximately \$1.2 billion. Data gained from developments of the test and pilot scale units for that program can be useful in facilitating the development of units to meet the listed power requirements.

It is anticipated that the 1 and 8 hour listed requirements for 10 and 50 Mw can be developed by 1985, and the continuous operating requirements can be developed by 1990. The overall costs of development of 10 and 50 Mw MHD plants meeting the listed requirements are estimated at approximately \$400 million.

4.0 References

1. "ECAS - General Electric Phase II Final Report, Advanced Energy Conversion Systems - Conceptual Designs, Part 3, Open Cycle Gas Turbines and Open Cycle MHD" by L. P. Harris and R. P. Shah; NASA-CR134949, Volume II, Part 3; December, 1976 (General Electric SRD-76-064-2)

2. "MHD Power Generation - Selected Problems of Combustion MHD Generators" by R. Bunde, H. Munterbruch, J. Raeder, R. Volk, G. Zankle; Editor, J. Raeder; Published by Springer-Verlag (Berlin, Heidelberg, New York)

3. "ECAS - General Electric Phase II Final Report, Volume III, Research and Development Plans and Implementation Assessment" by R. R. Bass, et al.; NASA-CR134949, Volume III; December, 1976 (General Electric SRD076-064-3)

4. "MHD Power Generation Development Program," EPRI Report No. 97, Final Report, June, 1976, prepared by Avco Everett Research Laboratory, Inc.

SECTION XII

THERMIONIC GENERATOR (CHEMICAL FUEL)

1.0 SYSTEM DESCRIPTION

1.1 Identification of Type of System

Fuel Converter: Oil-fired combustor

Energy Converter: Cesium-vapor thermionic converter for 10 kw to 750 kw requirements and cesium-vapor thermionic converter with steam bottoming plant for 10 Mw to 50 Mw requirements

Fuel: No. 2 distillate fuel oil

1.2 System Definition

The principle of thermionic conversion derives from the phenomena that current can be made to flow between two electrodes at different temperatures in a vacuum.

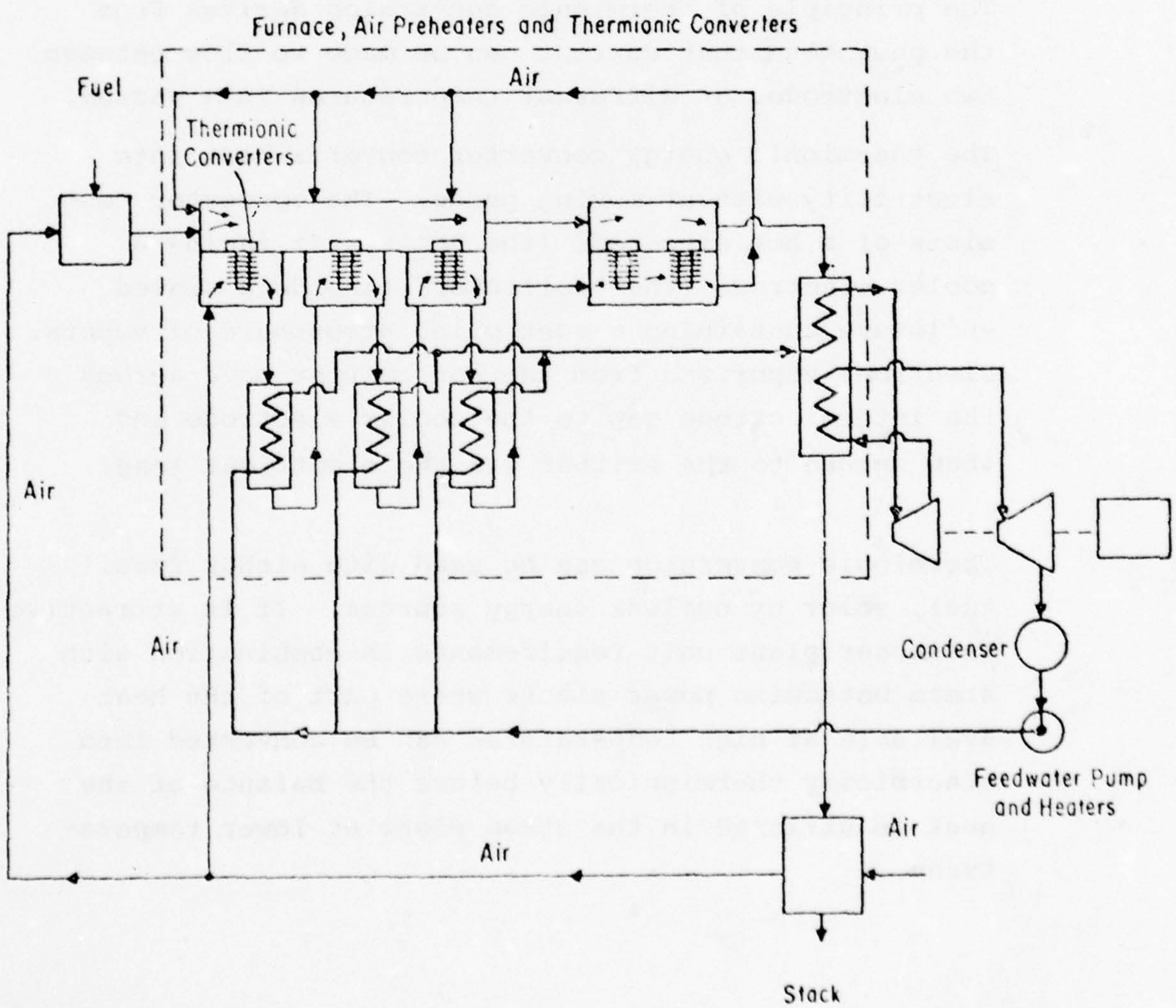
The thermionic energy converter converts heat into electricity without moving parts. The converter consists of a hot electrode (the "emitter") facing a cooler electrode (the "collector") inside a sealed enclosure containing a controlled atmosphere of vapors. Electrons vaporized from the hot emitter move across the interelectrode gap to the cooler electrode and then return to the emitter via the electrical load.

Thermionic conversion can be used with either fossil fuel, solar or nuclear energy sources. It is attractive in larger plant unit requirements in combination with steam bottoming power plants where part of the heat available at high temperatures can be converted into electricity thermionically before the balance of the heat is utilized in the steam plant at lower temperatures.

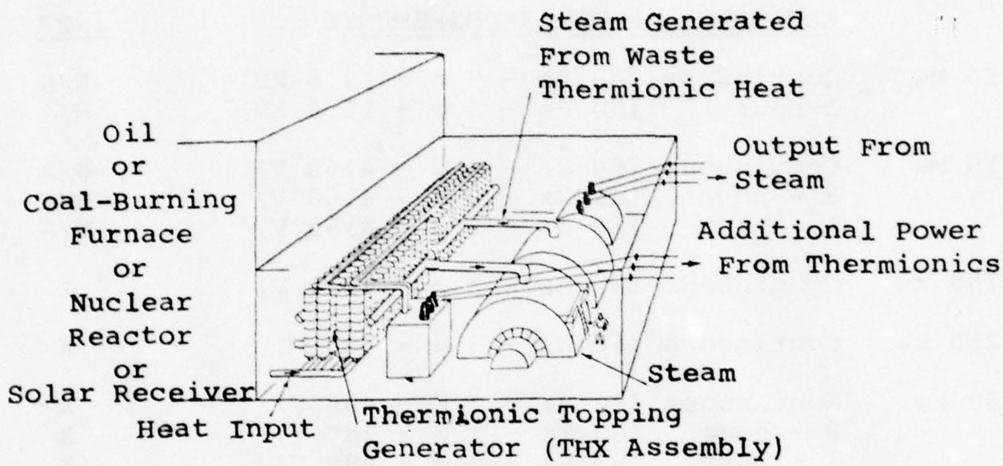
The integrated thermionic central station power converter system consists of several major components. These include:

Thermionic Heat Exchanger Modules
Inverters
Steam Turbine-Generator
Furnace System
High-Temperature Air Heaters
Finishing Superheater
Emission Control System
Wet Cooling Towers

A schematic flow diagram illustrating a thermionic converter with steam bottoming plant is illustrated below.



1.3 Physical Description



THERMIONIC POWER PLANT

Figure 17. Conceptual design by Rasor Associates, Inc.

2.0 LIST OF REQUIREMENTS AND TIME FRAMES

This power system is applicable to the following electrical power requirements as marked. The date listed indicates the earliest time when the system is expected to be available for purchase.

	ELECTRICAL POWER REQUIREMENTS	CASE I 1990	CASE II 1990
50 Mw	Continuous (60 Hz - 3 ø - 13.8 kV)	N/A	X
	1-hour (60 Hz - 3 ø - 13.8 kV)	N/A	X
10 Mw	Continuous (60 Hz - 3 ø - 4160 V)	N/A	X
	8 - hour (60 Hz - 3 ø - 4160 V)	N/A	X
	1 - hour (60 Hz - 3 ø - 4160 V)	N/A	X
750 kw	Continuous (60 Hz - 3 ø - 4160 V)	X	N/A
250 kw	Continuous (60 Hz - 3 ø - 480 V)	X	N/A
50 kw	Continuous (60 Hz - 3 ø - 480 V)	X	N/A
	8 - hour (60 Hz - 3 ø - 480 V)	X	N/A
	1 - hour (60 Hz - 3 ø - 480 V)	X	N/A
10 kw	Continuous #1 (DC - 28 V)	X	N/A
	Continuous #2 (60 Hz - 3 ø - 240 V)	X	N/A
	Continuous #3 (60 Hz - 1 ø - 240 V)	X	N/A
	Continuous #4 (60 Hz - 1 ø - 120 V)	X	N/A
	8 - hour #1 (DC - 28 V)	X	N/A
	8 - hour #2 (60 Hz - 3 ø - 240 V)	X	N/A
	1 - hour (60 Hz - 3 ø - 240 V)	X	N/A

CASE I : Without steam bottoming plant

CASE II: With steam bottoming plant

3.0 PARAMETERS

3.1 Acquisition Cost (1977 Dollars)

Requirement	($ x 10^6) 1990
50 Mw Cont.	$ 145.3
1 hr.	130.7
10 Mw Cont.	59.1
8 hr.	56.1
1 hr.	53.2
750 kw Cont.	13.3
250 kw Cont.	6.32
50 kw Cont.	2.18
8 hr.	2.07
1 hr.	1.96
10 kw Cont. #1	0.737
Cont. #2	0.737
Cont. #3	0.737
Cont. #4	0.737
8 hr. #1	0.700
8 hr. #2	0.700
1 hr.	0.663

3.2 Life Cycle Cost (1977 Dollars)

The life cycle cost (LCC) formula applicable to this system is:

LCC = AC + FC + OMC

where AC = Acquisition Cost (see Section 3.1)

FC = Total Fuel Cost over System Lifetime (see Section 3.6)

OMC = Operation and Maintenance Cost over System Lifetime (see Section 3.15)

Requirement	1990 LCC (1977 $'s)	1990 LCC/yr (1977 $'s)
50 Mw Cont.	735,000,000	24,500,000
1 hr.	183,000,000	6,100,000
10 Mw Cont.	184,000,000	6,140,000
8 hr.	121,000,000	4,040,000
1 hr.	65,400,000	2,180,000
750 kw Cont.	30,400,000	1,012,000
250 kw Cont.	12,400,000	413,000
50 kw Cont.	3,560,000	119,000
8 hr.	2,830,000	94,000
1 hr.	2,140,000	71,400
10 kw Cont. #1	1,040,000	34,900
Cont. #2	1,040,000	34,900
Cont. #3	1,040,000	34,900
Cont. #4	1,040,000	34,900
8 hr. #1	897,000	29,900
8 hr. #2	897,000	29,900
1 hr.	709,000	23,600

3.3 Lifetime (Years)

Requirement	1990
50 Mw Cont.	30 yrs.
1 hr.	30
10 Mw Cont.	30
1 hr.	30
750 kw Cont.	30
250 kw Cont.	30
50 kw Cont.	30
8 hr.	30
1 hr.	30
10 kw Cont.#1	30
Cont.#2	30
Cont.#3	30
Cont.#4	30
8 hr.#1	30
8 hr.#2	30
1 hr.	30

3.4 Volume/Size

DATA NOT AVAILABLE

#.8 Weight

DATA NOT AVAILABLE

3.6 Fuel

Fuel Utilization

Requirement	Amount Per Year	
	lb/yr	kg/yr
50 Mw Cont.	164,000,000	74,000,000
1 hr.	9,800,000	4,450,000
10 Mw Cont.	32,700,000	14,800,000
8 hr.	15,700,000	7,100,000
1 hr.	2,000,000	910,000
750 kw Cont.	4,100,000	1,860,000
250 kw Cont.	1,400,000	640,000
50 kw Cont.	280,000	130,000
8 hr.	130,000	59,000
1 hr.	17,000	7,700
10 kw Cont. #1	54,000	24,500
Cont. #2	54,000	24,500
Cont. #3	54,000	24,500
Cont. #4	54,000	24,500
8 hr. #1	26,000	11,800
8 hr. #2	26,000	11,800
1 hr.	3,200	1,450

Fuel Costs

Requirement	Amount Per Year gal.	Amount Per Year liters	Average Cost Per Year (1977 Dollars)
50 Mw Cont.	22,900,000	86,700,000	16,600,000
1 hr.	1,370,000	5,200,000	990,000
10 Mw Cont.	4,550,000	17,200,000	3,330,000
8 hr.	2,190,000	8,300,000	1,590,000
1 hr.	273,000	1,000,000	198,000
750 kw Cont.	570,000	2,200,000	413,000
250 kw Cont.	189,000	720,000	137,000
50 kw Cont.	39,000	150,000	28,000
8 hr.	18,000	68,000	13,000
1 hr.	2,300	8,700	1,700
10 kw Cont. #1	7,500	28,000	5,400
Cont. #2	7,500	28,000	5,400
Cont. #3	7,500	28,000	5,400
Cont. #4	7,500	28,000	5,400
8 hr. #1	3,600	13,600	2,600
8 hr. #2	3,600	13,600	2,600
1 hr.	440	1,670	320

3.7 Environmental Constraints

The environmental constraints of the power system are indicated in the following tabulation:

X amount of uncontrolled emission

Y Amount of pollution which would be emitted with no controls

Z Degree of difficulty in meeting more strict regulations

Key: blank - none
0 - minor
◐ - moderate
● - major

* Case I/Case II

Case I Without Steam Bottoming Plant

Case II With Steam Bottoming Plant

Emissions	X	Y	Z
Thermal Discharge (a)	●/◐*	-/-	-/-
Thermal Discharge (b)	-/●	-/●	-/●
Air Pollution			
CO	0/0	-/-	0/0
HC	0/0	-/-	0/0
NO_x	◐/0	-/-	●/●
SO_x	◐/◐	-/-	◐/◐
Particulates	0/0	0/0	◐/◐
Noise	0/◐	0/◐	0/◐
Solid Waste	-/-	-/-	-/-
Chemical Waste	-/-	-/-	-/-
Radioactive Waste	-/-	-/-	-/-

Notes: (a) system is air or water cooled; heat rejected directly to atmosphere.
(b) system is water cooled; heat rejected to body of water or cooling tower. Water source and/or make-up required.

3.8 Location Constraints

The locational limitations of the power system, and the degree of difficulty in overcoming these limitations are indicated in the following tabulation.

— - no difficulty

O - minor difficulty

◐ - major difficulty

● - overriding limitation

LOCATION RESTRAINT	Case I	Case II
Water required for cooling	O	◐
Water required for process	O	◐
Manning required during operation	O	●
Fuel deliveries required	●	●
Adequate solar insolation required	-	-
Adequate wind speed required	-	-
Isolation from population required	-	-
Electricity required for charging	-	-

Case I Without Steam Bottoming Plant

Case II With Steam Bottoming Plant

3.9 Operational Constraints

The tabulated operating characteristics are applicable to the power system as indicated.

— - Characteristic not observed in system operation

O - Characteristic has minor effect on system performance

◐ - Characteristic has moderate effect on system performance

● - Characteristic has major effect on system performance

Operational Restraint	Case I	Case II
Efficiency reduction at part load	O	O
Part load capability limitation	O	O
Dependence on solar insolation	-	-
Dependence on wind consistency	-	-
Overload capacity limitations	◐	◐
Delayed response to rapid load changes	O	◐
Life reduction from frequent rapid load changes	O	◐

Case I Without Steam Bottoming Plant

Case II With Steam Bottoming Plant

3.10 System Efficiency

Requirement		Efficiency %
50 Mw	Cont.	33
	1 hr.	33
10 Mw	Cont.	33
	8 hr.	33
	1 hr.	33
750 kw	Cont.	20
250 kw	Cont.	20
50 kw	Cont.	20
	8 hr.	20
	1 hr.	20
10 kw	Cont. #1	20
	Cont. #2	20
	Cont. #3	20
	Cont. #4	20
	8 hr. #1	20
	8 hr. #2	20
	1 hr.	20

3.11 Type of System

50 & 10 MW: Thermionic with steam bottoming

750 KW & Below: Thermionic

Selected Requirements	Mobile	Trans-portable	Fixed	Construction Time (years)
50 Mw Cont.			X	Data
1 hr.			X	
				not
10 Mw Cont.			X	
8 hr.			X	available
1 hr.			X	
750 kw Cont.	X			
250 kw Cont.	X			
50 kw Cont.	X			
8 hr.	X			
1 hr.	X			
10 kw Cont. #1	X			
Cont. #2	X			
Cont. #3	X			
Cont. #4	X			
8 hr. #1	X			
8 hr. #2	X			
1 hr.	X			

3.12 Start-up/Shut-down Time

Requirement	Start-up/Shut-down Time
50 Mw Cont.	1 hr.
1 hr.	1 hr.
10 Mw Cont.	1 hr.
8 hr.	1 hr.
1 hr.	1 hr.
750 kw Cont.	15 min.
250 kw Cont.	15 min.
50 kw Cont.	15 min.
8 hr.	15 min.
1 hr.	15 min.
10 kw Cont. #1	15 min.
Cont. #2	15 min.
Cont. #3	15 min.
Cont. #4	15 min.
8 hr. #1	15 min.
8 hr. #2	15 min.
1 hr.	15 min.

3.13 Growth Potential

This system does have some growth potential since the thermionic generator itself is comprised of a number of modular elements. However, the growth potential is limited by the extent to which other components such as the combustor are either oversized or capable of being modified.

3.14 Reliability

The tabulated conditions exist in the power system to the extent indicated.

— - Condition does not exist in system

O - Condition exists, but its extent is sufficiently minor as to have minimal effect on system performance or reliability

◐ - Condition exists, and its extent is sufficient to have a moderate effect on system performance or reliability

● - Condition exists and is a governing factor in determining system performance and reliability.

Conditions	Case I	Case II
Numerous moving parts	O	●
High temperature operation	●	●
High stress levels	-	O
High radiation level	-	-
Corrosive attack	◐	◐
Thermal cycling	O	O
Non-modular design	O	●
Solar insolation required	-	-
Wind required	-	-

Case I Without Steam Bottoming Plant

Case II With Steam Bottoming Plant

3.15 Maintenance and Operation

A. Operation and Maintenance Costs and Average Overhaul Duration

Requirement	Cost Per Year	Personnel Required Continuously
50 Mw Cont.	3,060,000	Yes
1 hr.	750,000	Yes
10 Mw Cont.	840,000	Yes
8 hr.	580,000	Yes
1 hr.	210,000	Yes
750 kw Cont.	156,000	No
250 kw Cont.	64,700	No
50 kw Cont.	17,900	No
8 hr.	12,400	No
1 hr.	4,400	No
10 kw Cont. #1	4,900	No
Cont. #2	4,900	No
Cont. #3	4,900	No
Cont. #4	4,900	No
8 hr. #1	4,000	No
8 hr. #2	4,000	No
1 hr.	1,200	No

3.16 Other Energy Production

Requirement	Thermal Energy Availability	
	10^3 Btu/hr	kw (thermal)
50 Mw Cont.	204,780	60,000
1 hr.	204,780	60,000
10 Mw Cont.	40,956	12,000
8 hr.	40,956	12,000
1 hr.	40,956	12,000
750 kw Cont.	6,143	1,800
250 kw Cont.	2,048	600
50 kw Cont.	410	120
8 hr.	410	120
1 hr.	410	120
10 kw Cont. #1	82	24
Cont. #2	82	24
Cont. #3	82	24
Cont. #4	82	24
8 hr. #1	82	24
8 hr. #2	82	24
1 hr.	82	24

3.17 Availability of Raw Building Materials

Raw building materials are readily available for this type of power system.

3.18 Development

Data not available

4.0 REFERENCES

1. Hatsopoulos, G. N. and Huffman, F. N., "The Growth of Thermionic Energy Conversion", Proceedings of the 10th IECEC (1975).

2. Fitzpatrick, G. O., et. al., "Increased Central Station Power Plant Efficiency with a Thermionic Topping System", Proceedings of the 12th IECEC (1977).

3. "Comparative Study and Evaluation of Advanced Cycle Systems", prepared by General Electric Co. for EPRI, Research Project 235-1, Phase I Report, May 1976 (NTIS No. PB-254 392).

SECTION XIII

STEAM TURBINE GENERATOR (NUCLEAR FUEL)

1.0 SYSTEM DESCRIPTION

1.1 System Identification

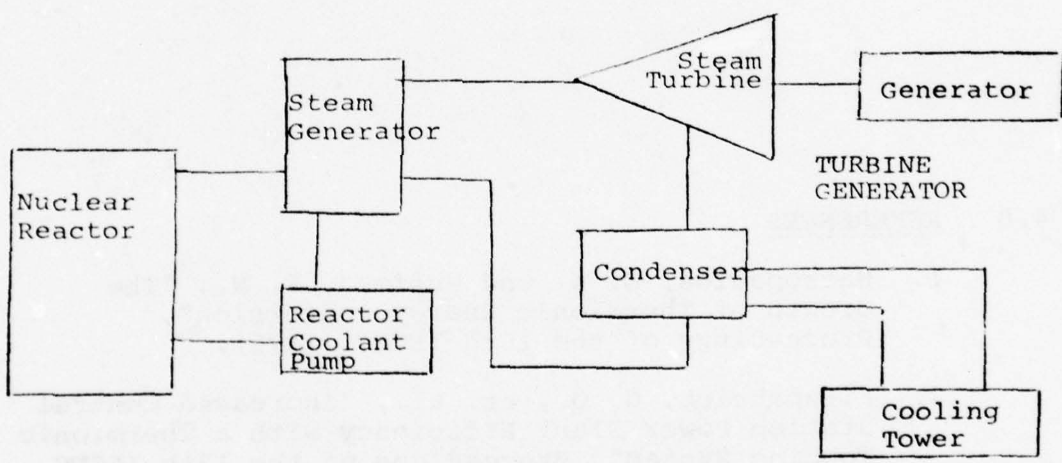
Fuel Converter - Pressurized water reactor

Energy Converter/Cycle - steam turbine/closed Rankine cycle

Fuel - Enriched uranium

Working Fluid - Water

1.2 System Definition



The major components of this plant consist of the integral nuclear reactor and steam generators, steam turbine generator, condensor and cooling water system and reactor and turbine building auxiliary systems. The plant is stationary and consists of the following major structures:

A. Reactor Building including containment

B. Turbine Generator Building

C. Diesel Generator Building

D. Cooling Towers and Circulating and Service Water Pumphouses

E. Control and Auxiliary Buildings

This type of system must be constructed on a fixed site. It cannot be purchased as a pre-packaged system. Various components are required which are manufactured by by a number of different companies. Therefore, a significant engineering effort is required to coordinate the system design and construction. The details of the system depend upon site conditions. Therefore, the system must be engineered for each site.

1.3 Physical Description

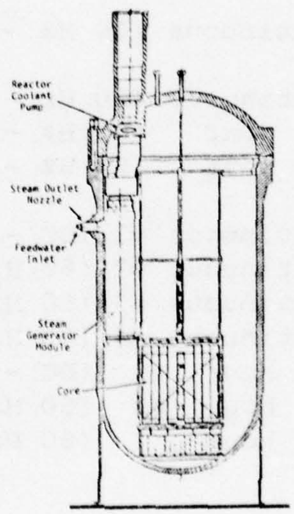


Figure 18. Babcock & Wilcox Co. design of Consolidated Nuclear Steam Generator for small size nuclear-electric power plants.

2.0 LIST OF REQUIREMENTS AND TIME FRAMES

This power system is applicable to the following electrical power requirements as marked. All data is based upon technology which is available in 1977.

	ELECTRICAL POWER REQUIREMENTS		1977
50 Mw	Continuous	(60 Hz - 3 ø - 13.8 kV)	X
	1-hour	(60 Hz - 3 ø - 13.8 kV)	X
10 MW	Continuous	(60 Hz - 3 ø - 4160 V)	N/A*
	8 - hour	(60 Hz - 3 ø - 4160 V)	N/A
	1 - hour	(60 Hz - 3 ø - 4160 V)	N/A
750 kw	Continuous	(60 Hz - 3 ø - 4160 V)	N/A
250 kw	Continuous	(60 Hz - 3 ø - 480 V)	N/A
50 kw	Continuous	(60 Hz - 3 ø - 480 V)	N/A
	8 - hour	(60 Hz - 3 ø - 480 V)	N/A
	1 - hour	(60 Hz - 3 ø - 480 V)	N/A
10 kw	Continuous #1	(DC - 28 V)	N/A
	Continuous #2	(60 Hz - 3 ø - 240 V)	N/A
	Continuous #3	(60 Hz - 1 ø - 240 V)	N/A
	Continuous #4	(60 Hz - 1 ø - 120 V)	N/A
	8 - hour #1	(DC - 28 V)	N/A
	8 - hour #2	(60 Hz - 3 ø - 240 V)	N/A
	1 - hour	(60 Hz - 3 ø - 240 V)	N/A

*The power requirements below 50 MW were not considered because the nuclear industry does not consider lower power levels economically feasible for this type of plant.

3.0 PARAMETERS

3.1 Acquisition Cost (1977 Dollars)

Requirement	1977
50 Mw Cont.	92,500,000
1 hr.	92,500,000

Acquisition Cost Breakdown

Structures and Site Improvements	17,415,000
Reactor Plant Equipment	24,900,000
Turbine Plant Equipment	11,800,000
Electric Plant Equipment	5,240,000
Misc. Plant Equipment	1,800,000
Engineering and Construction Management	15,950,000
20% Contingency	15,400,000
TOTAL	92,500,000

3.2 Life Cycle Cost (1977 Dollars)

The life cycle cost (LCC) formula applicable to this system is:

$$LCC = AC + FC + OMC$$

where AC = Acquisition Cost (see Section 3.1)

FC = Total Fuel Cost over System Lifetime (see Section 3.6)

OMC = Operation and Maintenance Cost over System Lifetime (see Section 3.15)

Requirement	LCC (1977)	LCC/yr (1977)
50 Mw Cont.	273,900,000	6,847,000
1 hr.	127,031,000	3,175,000

3.3 Lifetime (Years)

Requirement	1977
50 Mw Cont.	40
1 hr.	40

3.4 Volume/Size

Requirement	Approximate Land Area Required sq. ft.	sq. m.
50 Mw Cont.	90,000	8,400
1 hr.	90,000	8,400

In addition an exclusion area of approximately 1000 feet diameter from the center of the site is necessary. Exact area will depend upon site meteorological conditions.

3.5 Weight

Weight is not a relevant parameter for this type of system. Plant can not be air lifted to provide ground power to remote sites. Plant must be constructed at a fixed site.

3.6 Fuel

Requirement	Amount Per Year		Average Cost Per Year (1977 Dollars)	Time Between Deliveries
	tons	kg		
50 Mw Cont.	*	*	2,223,000	1 to 3 yrs.
1 hr.	*	*	92,625	None

* Refueling cycle is 3 years

Alternate Fuels

Reactor core can be adapted to utilize other fissionable fuels such as plutonium or thorium. Would entail additional development.

Fuel Availability

Uranium fuel will be available into the year 2000, development of breeder reactors are necessary to assure an adequate supply of fissionable materials.

3.7 Environmental Constraints

The environmental constraints of the power system are indicated in the following tabulation:

X amount of uncontrolled emission

Y Amount of pollution which would be emitted with no controls

Z Degree of difficulty in meeting more strict regulations

Key: blank - none

0 - minor

◐ - moderate

● - major

Emissions	X	Y	Z
Thermal Discharge (a)	-	-	-
Thermal Discharge (b)	●	●	●
Air Pollution			
CO	-	-	-
HC	-	-	-
NO_x	-	-	-
SO_x	-	-	-
Particulates	-	-	-
Noise	0	0	◐
Solid Waste	-	-	-
Chemical Waste	0	-	0
Radioactive Waste	◐	◐	◐

Notes: (a) system is air or water cooled; heat rejected directly to atmosphere.

(b) system is water cooled; heat rejected to body of water or cooling tower. Water source and/or make-up required.

3.8 Location Constraints

The locational limitations of the power system, and the degree of difficulty in overcoming these limitations are indicated in the following tabulation.

— - no difficulty

O - minor difficulty

◓ - major difficulty

● - overriding limitation

LOCATION RESTRAINT	
Water required for cooling	◓
Water required for process	◓
Manning required during operation	●
Fuel deliveries required	O
Adequate solar insolation required	-
Adequate wind speed required	-
Isolation from population required	●
Electricity required for charging	-

3.9 Operational Constraints

The tabulated operating characteristics are applicable to the power system as indicated.

— - Characteristic not observed in system operation

O - Characteristic has minor effect on system performance

◓ - Characteristic has moderate effect on system performance

● - Characteristic has major effect on system performance

Operational Restraint	
Efficiency reduction at part load	◓
Part load capability limitation	◓
Dependence on solar insolation	-
Dependence on wind consistency	-
Overload capacity limitations	◓
Delayed response to rapid load changes	◓
Life reduction from frequent rapid load changes	◓

3.10 System Efficiency

Requirement	1977
50 Mw Cont.	28%
1 hr.	28%

3.11 Type of System

Requirement	Mobile	Trans-portable	Fixed	Construction Time (years)
50 Mw Cont.			X	5*
1 hr.			X	5*

* Design and construction time for the first unit would be approximately eight years. Subsequent units would take 5 years.

3.12 Start-up/Shut-down Time

Selected Requirements	Start-up *	Shut-down
50 Mw Cont.	8 hr.	8 hr.
1 hr.	8 hr.	8 hr.

* Assuming cold start

3.13 Growth Potential

This type of power plant is non-modular by nature with the result that growth in capacity can be achieved only by adding an additional reactor and turbine.

If growth is planned from the beginning, equipment can be oversized for future additional capacity.

3.14 Reliability

The tabulated conditions exist in the power system to the extent indicated.

— - Condition does not exist in system

O - Condition exists, but its extent is sufficiently minor as to have minimal effect on system performance or reliability

◐ - Condition exists, and its extent is sufficient to have a moderate effect on system performance or reliability

● - Condition exists and is a governing factor in determining system performance and reliability.

Conditions	
Numerous moving parts	●
High temperature operation	O
High stress levels	O
High radiation level	O
Corrosive attack	O
Thermal cycling	◐
Non-modular design	●
Solar insolation required	-
Wind required	-

3.15 Maintenance and Operation

Requirement	Cost Per Year	Overhaul Duration (wks/yr)	Personnel Required Continuously
50 Mw Cont.	2,312,000	2	yes
1 hr.	770,000	1	yes

Operation and Maintenance Requirements

An operating crew must be in constant attendence during operation of the power plant.

A maintenance team must be available at the site to perform routine power plant maintenance. The maintenance crew would consist of machinists, instrument technicians, electricians, welders, etc.

Specialists such as health physicists, nuclear fuel management personnel, quality assurance engineers, and others are necessary to assist in plant operations and maintenance.

3.16 Other Energy Production

Requirement	10^6 Btu/hr	10^3 kw thermal
50 Mw Cont. 1 hr.	263 263	77.1 77.1

For a power plant of this type, thermal energy is normally discharged to the environment as low temperature condenser heat rejection to a body of water or to the atmosphere via wet or dry cooling towers. The electrical power output of the plant is maximized by making the temperatures of this thermal discharge as low as practicable. Temperatures would be suitable for the production of low pressure hot water only. If more thermal energy is needed, there are other options available, all of which would reduce the electrical power output of the power plant. Thermal energy can be made available in the form of hot water or steam over a wide range of conditions. However, the higher the temperature of the steam or hot water for a given amount of thermal energy, the lower the electric output.

3.17 Availability of Raw Building Materials

Raw building materials are readily available for this type of power plant.

3.18 Development

Development Program Cost and Duration

Requirement	Cost (1977 Dollars)	Time (Years)
50 Mw Cont.	30,000,000	3
1 hr.	30,000,000	3

Development costs for the first unit would be in addition to the capital cost of the plant. Development time would entail redesign of the reactor vessel, containment, core, components and licensing of the plant concept. The technology exists for building small nuclear plants but they are not commercially available.

4.0 References

The PE-CNSG A Small PWR to Provide Industrial Process Onsite Energy; W. R. Smith, Babcock & Wilcox 11th IECEC Proceedings, 769188, Sept. 12-17, 1976.

SECTION XIV

ORGANIC VAPOR TURBINE GENERATOR (NUCLEAR FUEL)

1.0 SYSTEM DESCRIPTION

1.1 System Identification

Fuel Converter - Fission Reactor

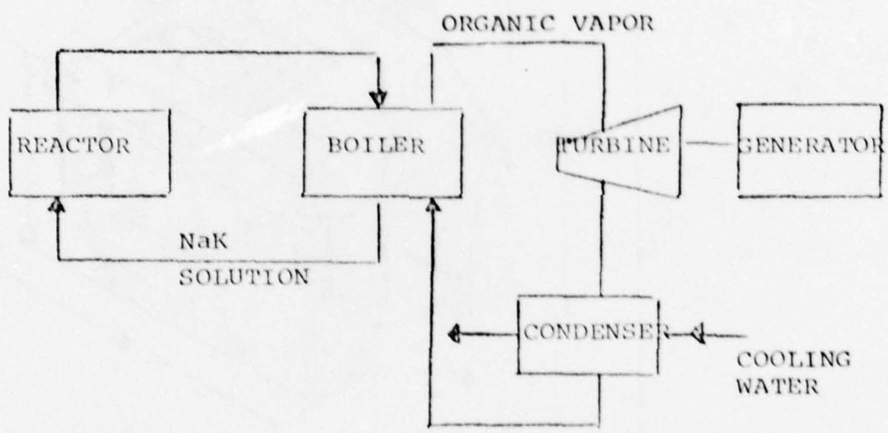
Energy Converter - Organic Vapor Turbine/Rankine Cycle

Fuel - Uranium Oxide

Working Fluid: Reactor - NaK, mixture of sodium and potassium

Turbine - Organic fluid

1.2 System Definition



SELF-CONTAINED POWER MODULE

The major components of this plant consist of a zirconium hydride (Zr H) reactor heat source, an organic Rankine power conversion system and a cooling water system to transfer the waste heat from the condenser. The plant consists of a single, self-contained module which can be installed at a fixed site. Site requirements consist of containment and shielding structure and miscellaneous cooling and inerting systems.

1.3 <u>Physical Description</u>

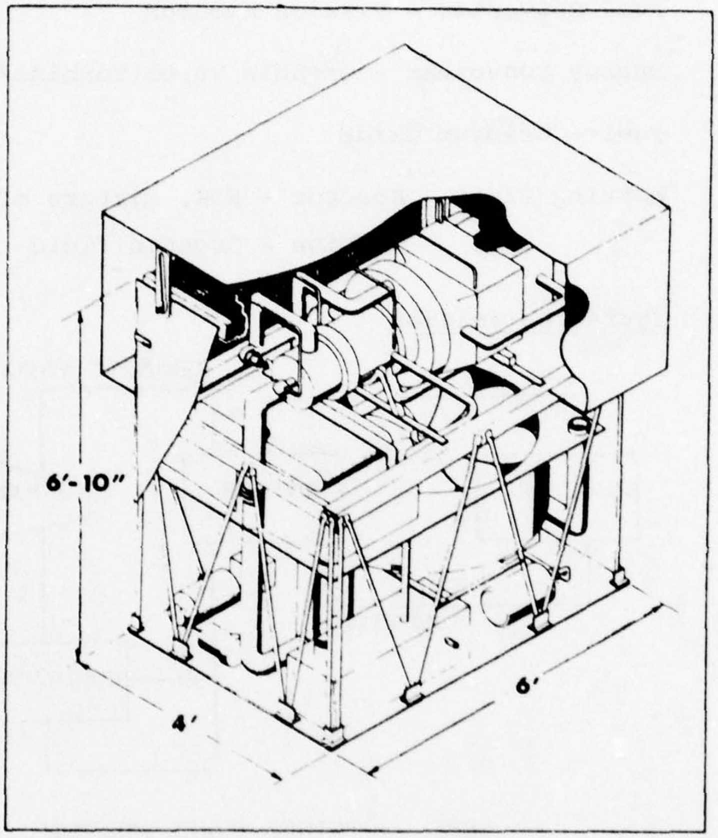


Figure 19. Sundstrand Corp. 150 KW organic vapor turbine-generator design.

2.0 LIST OF REQUIREMENTS AND TIME FRAMES

This power system is applicable to the following electrical power requirements as marked. The first date listed indicates the earliest time when the system will be available for purchase. Later dates indicate the point in time when significant improvements are expected.

	ELECTRICAL POWER REQUIREMENTS		1980
50 Mw	Continuous	(60 Hz - 3 ø - 13.8 kV)	N/A
	1-hour	(60 Hz - 3 ø - 13.8 kV)	N/A
10 MW	Continuous	(60 Hz - 3 ø - 4160 V)	N/A
	8 - hour	(60 Hz - 3 ø - 4160 V)	N/A
	1 - hour	(60 Hz - 3 ø - 4160 V)	N/A
750 kw	Continuous	(60 Hz - 3 ø - 4160 V)	X
250 kw	Continuous	(60 Hz - 3 ø - 480 V)	X
50 kw	Continuous	(60 Hz - 3 ø - 480 V)	X
	8 - hour	(60 Hz - 3 ø - 480 V)	X
	1 - hour	(60 Hz - 3 ø - 480 V)	X
10 kw	Continuous #1	(DC - 28 V)	N/A
	Continuous #2	(60 Hz - 3 ø - 240 V)	N/A
	Continuous #3	(60 Hz - 1 ø - 240 V)	N/A
	Continuous #4	(60 Hz - 1 ø - 120 V)	N/A
	8 - hour #1	(DC - 28 V)	N/A
	8 - hour #2	(60 Hz - 3 ø - 240 V)	N/A
	1 - hour	(60 Hz - 3 ø - 240 V)	N/A

Power levels above 750 kw and below 50 kw have not been considered since this is out of the range of the developmental work which has been carried out for the SNAP Programs.

3.0 PARAMETERS

3.1 Acquisition Cost (1977 Dollars)

Requirement	1980
750 kw Cont.	4,800,000
250 kw Cont.	2,709,000
50 kw Cont.	1,900,000
8 hr.	1,900,000
1 hr.	1,900,000

Acquisition Cost Breakdown

	50 KWe	250 KWe	750 KWe
Modular Power System	1,600,000	2,225,000	4,000,000
Structures and Cooling Systems	320,000	450,000	800,000
Total Capital Costs	1,900,000	2,700,000	4,800,000

3.2 Life Cycle Cost (1977 Dollars)

The life cycle cost (LCC) formula applicable to this system is:

$$LCC = AC + FC + OMC$$

where AC = Acquisition Cost (see Section 3.1)

FC = Total Fuel Cost over System Lifetime (see Section 3.6)

OMC = Operation and Maintenance Cost over System Lifetime (see Section 3.15)

Requirement	LCC (1980)	LCC/yr (1980)
750 kw Cont.	14,320,000	716,000
250 kw Cont.	8,220,000	411,000
50 kw Cont.	4,440,000	220,000
8 hr.	3,490,000	174,500
1 hr.	3,060,000	153,000

3.3 Lifetime (Years)

Requirement	1980
750 kw Cont.	20
250 kw Cont.	20
50 kw Cont.	20
8 hr.	20
1 hr.	20

3.4 Volume/Size

Requirement	Volume ft^3	Volume m^3
750 kw Cont.	502	14.2
250 kw Cont.	333	9.4
50 kw Cont.	194	5.4
8 hr.	194	5.4
1 hr.	194	5.4

The power system consists of a self contained unit in a cylindrical module which is transportable by air or ground transportation to a fixed site. The size of the site containment structure for each power module is given below.

50 kw	12' x 12'
250 kw	13.5' x 13.5'
750 kw	15' x 15'

3.5 Weight

Requirement	1980	
	lb	kg
750 kw Cont.	48,000	21,800
250 kw Cont.	28,400	12,800
50 kw Cont.	16,400	7,400
1 hr.	16,400	7,400
8 hr.	16,400	7,400

Table gives weight of each cylindrical power module for each power level.

3.6 Fuel

Requirement	Amount Per Year tons	kg	Average Cost Per Year (1977 Dollars)	Time Between Deliveries
750 kw Cont.	N/A	N/A	281,000	3 years
250 kw Cont.	N/A	N/A	163,000	3 years
50 kw Cont.	N/A	N/A	73,000	5 years
8 hr.	N/A	N/A	24,300	10 years
1 hr.	N/A	N/A	6,000	20 years

The fuel used is uranium zirconium hydride. Average burnup of the metallic uranium is .7 percent between refuelings which is on the order of every three to five years for the systems that operate continuously.

Alternate Fuels

Presently no alternate fuels are developed for this type of reactor.

Fuel Availability

Uranium in the quantities required for these small nuclear reactors would not be a problem beyond the year 2000. Marginal mining areas could be used.

3.7 Environmental Constraints

The environmental constraints of the power system are indicated in the following tabulation:

X amount of uncontrolled emission

Y Amount of pollution which would be emitted with no controls

Z Degree of difficulty in meeting more strict regulations

Key: blank - none

0 - minor

◐ - moderate

● - major

Emissions	X	Y	Z
Thermal Discharge (a)	-	-	-
Thermal Discharge (b)	●	●	●
Air Pollution			
CO	-	-	-
HC	-	-	-
NO_x	-	-	-
SO_x	-	-	-
Particulates	-	-	-
Noise	0	0	◐
Solid Waste	-	-	-
Chemical Waste	0	-	0
Radioactive Waste	◐	◐	◐

Notes: (a) system is air or water cooled; heat rejected directly to atmosphere.
(b) system is water cooled; heat rejected to body of water or cooling tower. Water source and/or make-up required.

Note: (Cont'd) Thermal Discharge type (b) is emitted to a liquid coolant, and then to a body of water or to the atmosphere.

System is self-contained and does not discharge pollutants to the environment. Refueling takes place at a facility designed to handle this operation.

3.8 Location Constraints

The locational limitations of the power system, and the degree of difficulty in overcoming these limitations are indicated in the following tabulation.

- — - no difficulty
- O - minor difficulty
- ◐ - major difficulty
- ● - overriding limitation

LOCATION RESTRAINT	
Water required for cooling	◐
Water required for process	-
Manning required during operation	O
Fuel deliveries required	O
Adequate solar insolation required	-
Adequate wind speed required	-
Isolation from population required	●
Electricity required for charging	-

3.9 Operational Constraints

The tabulated operating characteristics are applicable to the power system as indicated.

— - Characteristic not observed in system operation

○ - Characteristic has minor effect on system performance

◐ - Characteristic has moderate effect on system performance

● - Characteristic has major effect on system performance

Operational Restraint	
Efficiency reduction at part load	○
Part load capability limitation	○
Dependence on solar insolation	–
Dependence on wind consistency	–
Overload capacity limitations	◐
Delayed response to rapid load changes	◐
Life reduction from frequent rapid load changes	◐

3.10 System Efficiency

Requirement	1980
750 kw Cont.	27%
250 kw Cont.	25
50 kw Cont.	23
8 hr.	23
1 hr.	23

3.11 Type of System

Requirement	Mobile	Trans-portable	Fixed	Production Time (years)
750 kw Cont.			X	1
250 kw Cont.			X	1
50 kw Cont.			X	1
1 hr.			X	1
8 hr.			X	1

The system is installed at a fixed site. The modular system can be removed and used at other fixed sites. The system can be transported by truck, train, ship or aircraft as a single sealed unit.

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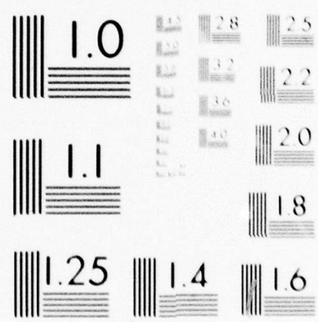

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3.12 Start-up/Shut-down Time

Requirement	Start-Up	Shut-down
750 kw Cont.	3 hr.	1 min.
250 kw Cont.	3 hr.	1 min.
50 kw Cont.	3 hr.	1 min.
1 hr.	3 hr.	1 min.
8 hr.	3 hr.	1 min.

3.13 Growth Potential

Power modules can be added to a site in increments of from 50 KWe to 750 KWe since each module is a self-contained system.

3.14 Reliability

The tabulated conditions exist in the power system to the extent indicated.

— - Condition does not exist in system

O - Condition exists, but its extent is sufficiently minor as to have minimal effect on system performance or reliability

◐ - Condition exists, and its extent is sufficient to have a moderate effect on system performance or reliability

● - Condition exists and is a governing factor in determining system performance and reliability.

Conditions	
Numerous moving parts	O
High temperature operation	O
High stress levels	O
High radiation level	O
Corrosive attack	-
Thermal cycling	O
Non-modular design	●
Solar insolation required	-
Wind required	-

3.15 Maintenance and Operation

Requirement	Cost Per Year	Overhaul Duration (wks/yr)	Personnel Required Continuously
750 kw Cont.	78,800	NA	No
250 kw Cont.	45,500	NA	No
50 kw Cont.	20,400	NA	No
8 hr.	20,400	NA	No
1 hr.	20,400	NA	No

Operation and Maintenance Requirements:

Every three to five years, the power module must be replaced. The used power module must be sent to a refueling facility for overhaul and refurbishment. The costs for these operations, which are in addition to the fuel costs, are presented in the above table. Maintenance of the power module cannot be performed at the user's site.

3.16 Other Energy Production

Requirement	10^6 Btu/hr	10^3 kw Thermal
750 kw Cont.	4.15	1.2
250 kw Cont.	1.53	0.45
50 kw Cont.	0.34	0.10
8 hr.	0.34	0.10
1 hr.	0.34	0.10

The above table presents the approximate waste heat available from the power module, which could supply heat to buildings. Temperatures are suitable for the production of low pressure hot water only.

3.17 Availability of Raw Building Materials

Raw building materials are readily available for this type of power supply.

3.18 Development

A. Development Program Cost and Duration

Requirement	Cost (1977 Dollars)	Time (Years)
750 kw Cont.	50,000,000	3
250 kw Cont.	40,000,000	3
50 kw Cont.	30,000,000	3
8 hr.	30,000,000	3
1 hr.	30,000,000	3

The zirconium hydride reactor with organic Rankine power conversion system is a developed technology with a history of SNAP reactor test experience.

The table above presents product development costs and time for engineering and prototype testing.

The development risk is minimal as proven technology would be utilized in the fabrication of these self-contained power systems.

Production time is on the order of one year or less for this type of unit.

4.0 References

(1) Letter and Data Package from A. B. Martin, Program Manager, Advanced Nuclear Systems, Rockwell International dated March 7, 1977

(2) Technical Paper "Subsea Nuclear Power Systems for Future Offshore Productions", A. B. Martin, Rockwell International.

(3) Telecon dated 3/15/77 from R. Reyer to A. B. Martin, Atomics International, Division of Rockwell International.

SECTION XV

GAS TURBINE GENERATOR (NUCLEAR FUEL)

1.0 SYSTEM DESCRIPTION

1.1 System Identification

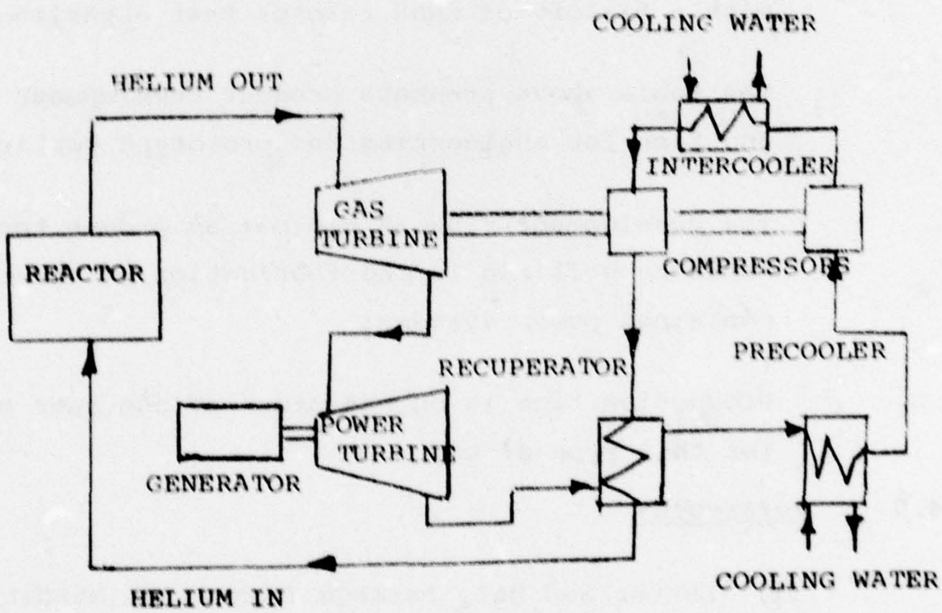
Fuel Converter: Gas Cooled Reactor

Energy Converter Cycle: Light Weight Gas Turbine/ Brayton Closed Cycle

Fuel: Uranium/Thorium

Working Fluid: Helium

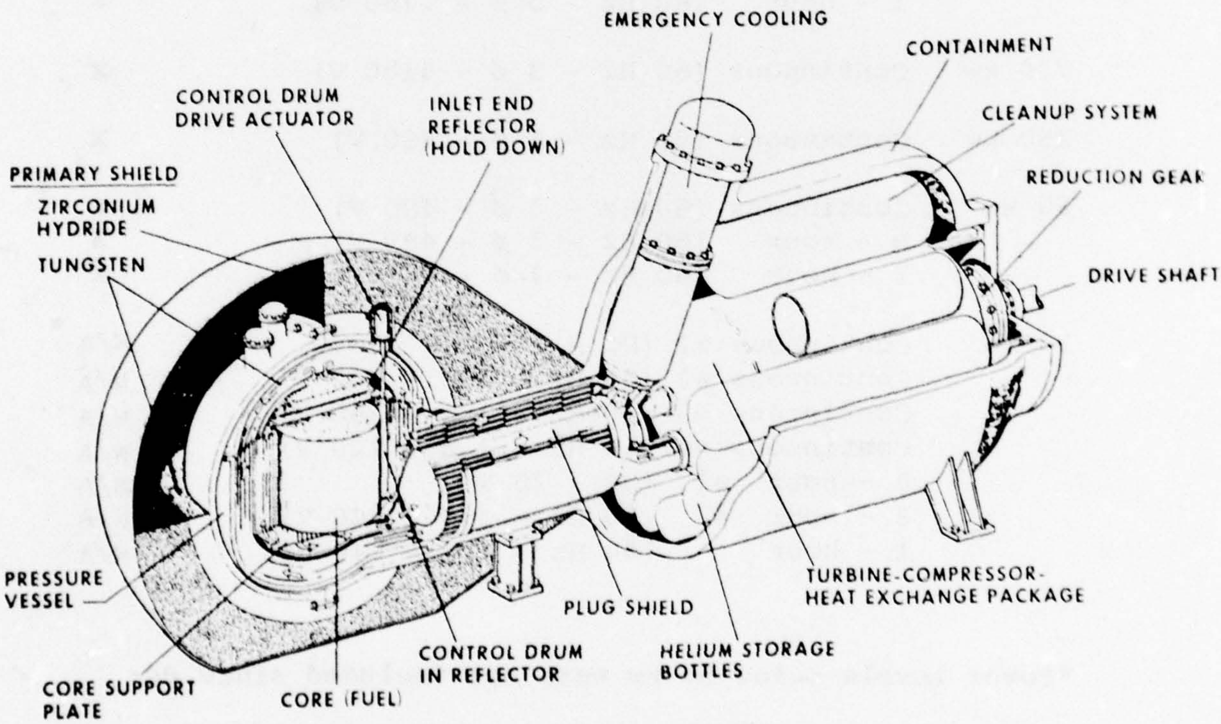
1.2 System Definition



The major components of this system consist of the gas cooled reactor, gas turbine including compressors, intercooler and generator, recuperator and precooler. Heat rejection from the precoolers and intercoolers is to an intermediate heat transfer system which in turn rejects heat to a cooling tower system. Site requirements consist of a containment and shielding structure and miscellaneous cooling and auxiliary systems.

1.3 Physical Description

Figure 20.



Westinghouse design of a light weight 15 MW nuclear-gas turbine power system (generator not shown)

2.0 LIST OF REQUIREMENTS AND TIME FRAMES

This power system is applicable to the following electrical power requirements as marked. The first date listed indicates the earliest time when the system will be available for purchase. Later dates indicate the point in time when significant improvements are expected.

ELECTRICAL POWER REQUIREMENTS

			1990
50 Mw	Continuous	(60 Hz - 3 ø - 13.8 kV)	X
	1-hour	(60 Hz - 3 ø - 13.8 kV)	X
10 MW	Continuous	(60 Hz - 3 ø - 4160 V)	X
	8 - hour	(60 Hz - 3 ø - 4160 V)	X
	1 - hour	(60 Hz - 3 ø - 4160 V)	X
750 kw	Continuous	(60 Hz - 3 ø - 4160 V)	X
250 kw	Continuous	(60 Hz - 3 ø - 480 V)	X
50 kw	Continuous	(60 Hz - 3 ø - 480 V)	X
	8 - hour	(60 Hz - 3 ø - 480 V)	X
	1 - hour	(60 Hz - 3 ø - 480 V)	X
10 kw	Continuous #1	(DC - 28 V)	N/A *
	Continuous #2	(60 Hz - 3 ø - 240 V)	N/A
	Continuous #3	(60 Hz - 1 ø - 240 V)	N/A
	Continuous #4	(60 Hz - 1 ø - 120 V)	N/A
	8 - hour #1	(DC - 28 V)	N/A
	8 - hour #2	(60 Hz - 3 ø - 240 V)	N/A
	1 - hour	(60 Hz - 3 ø - 240 V)	N/A

*Power levels below 50 kw were not included since development below this level is not being considered by potential manufacturers of the power system.

3.0 PARAMETERS

3.1 Acquisition Cost (1977 Dollars)

Requirement	1990
50 Mw Cont.	50,000,000
1 hr.	50,000,000
10 Mw Cont.	20,000,000
8 hr.	20,000,000
1 hr.	20,000,000
*750 kw Cont.	4,800,000
*250 kw Cont.	2,700,000
*50 kw Cont.	1,900,000
8 hr.	1,900,000
1 hr.	1,900,000

* Cost data for these systems not developed, assumed similar to zirconium hydride reactor, organic vapor turbine generator (Chapter XII).

Acquisition Cost Breakdown

	50 MWe	10 MWe
Power Conversion Package (Reactor, Turbine & Containment)	40,000,000	15,000,000
Balance of Plant (Generator, Cooling Water Systems, Engineering)	10,000,000	5,000,000
Total Costs	50,000,000	20,000,000

3.2 Life Cycle Cost (1977 Dollars)

The life cycle cost (LCC) formula applicable to this system is:

LCC = AC + FC + OMC

where AC = Acquisition Cost (see Section 3.1)

FC = Total Fuel Cost over System Lifetime (see Section 3.6)

OMC = Operation and Maintenance Cost over System Lifetime (see Section 3.15)

Selected Requirements	LCC (1990)	LCC/yr (1990)
50 Mw Cont.	119,530,000	18,400,000
1 hr.	57,400,000	1,913,000
10 Mw Cont.	44,000,000	6,760,000
8 hr.	45,400,000	2,270,000
1 hr.	24,300,000	810,000
750 kw Cont.	6,944,000	1,068,000
250 kw Cont.	3,808,000	586,000
50 kw Cont.	2,391,000	368,000
8 hr.	2,400,000	120,000
1 hr.	2,088,000	69,600

3.3 Lifetime (Years)

Requirement	1990
50 Mw Cont.	6.5
1 hr.	30
10 Mw Cont.	6.5
8 hr.	20
1 hr.	30
750 kw Cont.	6.5
250 kw Cont.	6.5
50 kw Cont.	6.5
50 kw 8 hr.	20
50 kw 1 hr.	30

3.4 Volume/Size

Volume of total system envelope

Requirement	1990	
	ft^3	m^3
50 Mw Cont.	6100	173
50 Mw 1 hr.	6100	173
10 Mw Cont.	1200	34
10 Mw 8 hr.	1200	34
10 Mw 1 hr	1200	34
750 kw Cont.	123	4
250 kw Cont.	95	3
50 kw Cont.	70	2
50 kw 8 hr.	70	2
50 kw 1 hr.	70	2

3.5 Weight

Requirement	1990	
	lb	kg
50 Mw Cont.	950,000	430,000
1 hr.	950,000	430,000
10 Mw Cont.	450,000	203,000
8 hr.	450,000	203,000
1 hr.	450,000	203,000
750 kw Cont.	48,000	22,000
250 kw Cont.	28,400	13,000
50 kw Cont.	16,400	7,500
50 kw 8 hr.	16,400	7,500
50 kw 1 hr.	16,400	7,500

3.6 Fuel

Requirements	Amount Per Year: tons	Amount Per Year: kg	Average Cost Per Year (1977 Dollars)	Refuelings
50 Mw Cont.	*	*	2,437,000	1.6 years
1 hr.	*	*	130,000	No Refueling
10 Mw Cont.	*	*	500,000	1.6 years
8 hr.	*	*	160,000	5 years
1 hr.	*	*	26,600	No Refueling
750 kw Cont.	*	*	281,000	3 years
250 kw Cont.	*	*	163,000	5 years
50 kw Cont.	*	*	73,000	5 years
8 hr.	*	*	24,300	10 years
1 hr.	*	*	6,000	20 years

Alternate Fuels

The fuels used can be uranium or thorium.

Fuel Availability

The availability of uranium 235 beyond the year 2000 is questionable. Thorium 232 is presently not being consumed to any great extent. The availability of thorium as a fuel is good.

3.7 Environmental Constraints

The environmental constraints of the power system are indicated in the following tabulation:

X amount of uncontrolled emission

Y Amount of pollution which would be emitted with no controls

Z Degree of difficulty in meeting more strict regulations

Key: blank - none

0 - minor

◐ - moderate

● - major

Emissions	X	Y	Z
Thermal Discharge (a)	-	-	-
Thermal Discharge (b)	●	●	●
Air Pollution			
CO	-	-	-
HC	-	-	-
NO_x	-	-	-
SO_x	-	-	-
Particulates	-	-	-
Noise	0	0	◐
Solid Waste	-	-	-
Chemical Waste	0	-	0
Radioactive Waste	◐	◐	◐

Notes: (a) system is air or water cooled; heat rejected directly to atmosphere.

(b) system is water cooled; heat rejected to body of water or cooling tower. Water source and/or make-up required.

Liquid and gaseous radioactive waste treatment and disposal system are required. Dry or wet cooling towers are required to control thermal discharges. Chemical treatment and neutralization systems are required to control chemical discharges.

Environmental impact of system is minimal with respect to emissions. Discharges to the environment due to routine operations is less than fossil fuel plants. Impact of accident is greater than fossil fuel plants.

Emergency plans must be established for handling on site and off site occurances for nuclear plant accidents.

3.8 Location Constraints

The locational limitations of the power system, and the degree of difficulty in overcoming these limitations are indicated in the following tabulation.

— - no difficulty

O - minor difficulty

◐ - major difficulty

● - overriding limitation

LOCATION RESTRAINT	
Water required for cooling	◐
Water required for process	-
Manning required during operation	●
Fuel deliveries required	O
Adequate solar insolation required	-
Adequate wind speed required	-
Isolation from population required	●
Electricity required for charging	-

3.9 Operational Constraints

The tabulated operating characteristics are applicable to the power system as indicated.

— - Characteristic not observed in system operation

O - Characteristic has minor effect on system performance

◐ - Characteristic has moderate effect on system performance

● - Characteristic has major effect on system performance

Operational Restraint	
Efficiency reduction at part load	O
Part load capability limitation	◐
Dependence on solar insolation	-
Dependence on wind consistency	-
Overload capacity limitations	◐
Delayed response to rapid load changes	◐
Life reduction from frequent rapid load changes	◐

3.10 System Efficiency

Requirement	1990
50 Mw Cont.	30%
1 hr.	30%
10 Mw Cont.	30%
8 hr.	30%
1 hr.	30%
750 kw Cont.	30%
250 kw Cont.	30%
50 kw Cont.	30%
8 hr.	30%
1 hr.	30%

3.11 Type of System

Requirement	Mobile	Trans-portable	Fixed	Construction Time (years)
50 Mw Cont.			X	3
1 hr.			X	3
10 Mw Cont.			X	3
8 hr.			X	3
1 hr.			X	3
750 kw Cont.			X	1
250 kw Cont.			X	1
50 kw Cont.			X	1
8 hr.			X	1
1 hr.			X	1

3.12 Start-up/Shut-down Times

Requirement	Start-up	Shut-down
50 Mw Cont.	1 hr.	1 hr.
1 hr.	1 hr.	1 hr.
10 Mw Cont.	1 hr.	1 hr.
8 hr.	1 hr.	1 hr.
1 hr.	1 hr.	1 hr.
750 kw Cont.	1 hr.	1 hr.
250 kw Cont.	1 hr.	1 hr.
50 kw Cont.	1 hr.	1 hr.
8 hr.	1 hr.	1 hr.
1 hr.	1 hr.	1 hr.

3.13 Growth Potential

This type of power plant is non-modular in nature with the result that growth in capacity can be achieved only by adding an additional reactor and turbine. If growth is planned from the beginning, equipment can be oversized for future additional capacity.

3.14 Reliability

The tabulated conditions exist in the power system to the extent indicated.

— - Condition does not exist in system

O - Condition exists, but its extent is sufficiently minor as to have minimal effect on system performance or reliability

◐ - Condition exists, and its extent is sufficient to have a moderate effect on system performance or reliability

● - Condition exists and is a governing factor in determining system performance and reliability.

Conditions	
Numerous moving parts	●
High temperature operation	O
High stress levels	O
High radiation level	O
Corrosive attack	-
Thermal cycling	◐
Non-modular design	●
Solar insolation required	-
Wind required	-

3.15 Maintenance and Operation

Requirement	Cost Per Year	Overhaul Duration (wks/yr)	Personnel Required Continuously
50 Mw Cont.	8,300,000	*	Yes
1 hr.	116,000	*	Yes
10 Mw Cont.	4,070,000	*	Yes
8 hr.	1,070,000	*	Yes
1 hr.	116,000	*	Yes
750 kw Cont.	48,900	*	No
250 kw Cont.	7,400	*	No
50 kw Cont.	2,540	*	No
8 hr.	675	*	No
1 hr.	250	*	No

* Overhaul duration is approximately three months

After every 10,000 full power hours, the system has to be completely overhauled. Costs for this overhaul equal one-third of the capital cost of the system. This concept is similar to the U.S. Air Force jet engine overhaul program after a similar amount of operation.

Operation and Maintenance Requirements:

For the larger plants (50 Mw, 10 Mw) an operating crew must be in constant attendance during operation of the plant.

A maintenance team must be available at the site to perform routine power plant maintenance.

Specialists such as health physicists, nuclear fuel management personnel, quality assurance engineers and others are necessary to assist in plant operations and maintenance.

3.16 Other Energy Production

Requirement	10^6 Btu/hr	10^3 kw Thermal
50 Mw Cont.	239	70
1 hr.	239	70
10 Mw Cont.	47.8	14
8 hr.	47.8	14
1 hr.	47.8	14
750 kw Cont.	3.58	1.50
250 kw Cont.	1.20	0.35
50 kw Cont.	0.239	0.07
8 hr.	0.239	0.07
1 hr.	0.239	0.07

Temperatures are suitable for the production of low pressure hot water only.

3.17 Availability of Raw Building Materials

Raw building materials are readily available for this type of power plant.

3.18 Development

A. Development Program Cost and Duration

Requirements	Cost (1977 Dollars)	Time (Years)
50 Mw Cont.	2.25×10^6	15
1 hr.	2.25×10^6	15
10 Mw Cont.	2.25×10^6	15
8 hr.	2.25×10^6	15
1 hr.	2.25×10^6	15
750 kw Cont.	2.25×10^6	15
250 kw Cont.	2.25×10^6	15
50 kw Cont.	2.25×10^6	15
8 hr.	2.25×10^6	15
1 hr.	2.25×10^6	15

Development costs include $.5 \times 10^9$ dollars for facilities. Development costs for each size unit would be significantly less than for the first unit developed for a specific power level.

4.0 **References**

1. Gas Cooled Reactors for Space Power Plants; R. E. Thompson, AIAA paper 77-490, AIAA conference, March 1-3, 1977.

2. Maritime Applications of an Advanced Gas-Cooled Reactor Propulsion System, R. E. Thompson, SNAME 1977 Spring Meeting, May 25-27, 1977.

3. Letter 7/21/77 from R. E. Thompson, Westinghouse, to R. J. Reyer, Burns and Roe, Inc.

SECTION XVI

GAS TURBINE GENERATOR (RADIOISOTOPE FUEL)

1.0 SYSTEM DESCRIPTION

1.1 System Identification

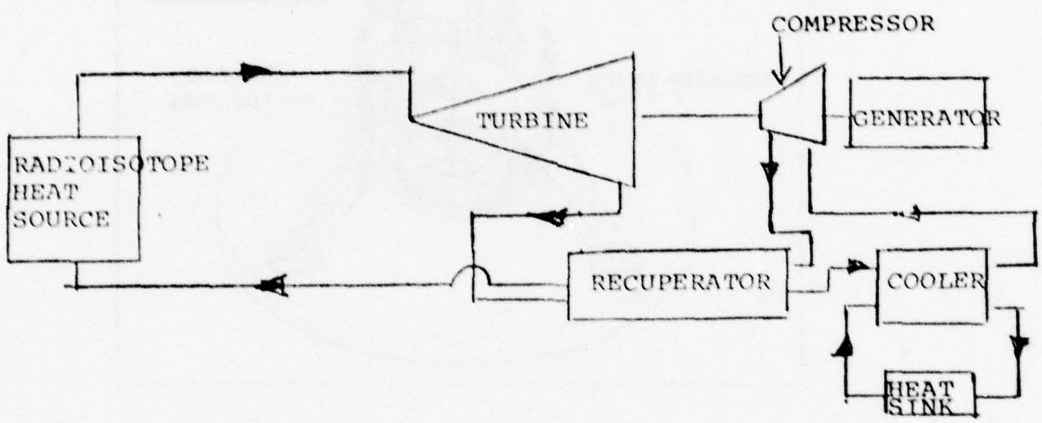
Fuel Converter: Radioisotope heat source.

Energy Converter/Cycle: Gas turbine power plant/closed Brayton cycle.

Fuel: Radioisotope.

Working Fluid: Inert gas mixture.

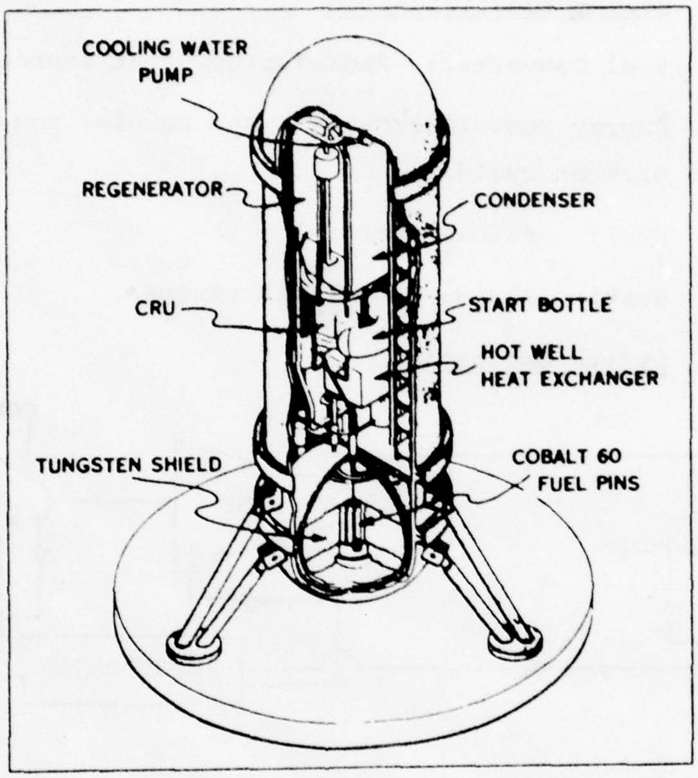
1.2 System Definition



The major components of the power system consist of the radioactive isotope heat source, the closed cycle gas turbine (including turbine, compressor, recuperator, and gas cooler), and a generator and associated controls. Two types of isotopes are considered; Pu^{238} and Co^{60}.

1.3 Physical Description

Figure 21.



Sundstrand Corp. design of a 3 KW Organic Rankine Cycle System Utilizing a Cobalt 60 Radioisotope Heat Source

2.0 LIST OF REQUIREMENTS AND TIME FRAMES

This power system is applicable to the following electrical power requirements as marked. The first date listed indicates the earliest time when the system will be available for purchase. Later dates indicate the point in time when significant improvements are expected.

	ELECTRICAL POWER REQUIREMENTS		1977
50 Mw	Continuous	(60 Hz - 3 ø - 13.8 kV)	N/A*
	1-hour	(60 Hz - 3 ø - 13.8 kV)	N/A
10 MW	Continuous	(60 Hz - 3 ø - 4160 V)	N/A
	8 - hour	(60 Hz - 3 ø - 4160 V)	N/A
	1 - hour	(60 Hz - 3 ø - 4160 V)	N/A
750 kw	Continuous	(60 Hz - 3 ø - 4160 V)	N/A
250 kw	Continuous	(60 Hz - 3 ø - 480 V)	N/A
50 kw	Continuous	(60 Hz - 3 ø - 480 V)	N/A
	8 - hour	(60 Hz - 3 ø - 480 V)	N/A
	1 - hour	(60 Hz - 3 ø - 480 V)	N/A
10 kw	Continuous #1	(DC - 28 V)	X
	Continuous #2	(60 Hz - 3 ø - 240 V)	X
	Continuous #3	(60 Hz - 1 ø - 240 V)	X
	Continuous #4	(60 Hz - 1 ø - 120 V)	X
	8 - hour #1	(DC - 28 V)	X
	8 - hour #2	(60 Hz - 3 ø - 240 V)	X
	1 - hour	(60 Hz - 3 ø - 240 V)	X

*Power requirements above 10 kw were not included since radioisotopic power is only considered practical for low power levels due to its high cost and the limited availability of radioactive isotopes.

3.0 PARAMETERS

3.1 Acquisition Cost (1977 Dollars)

Requirement	Pu^{238} Heat Source	Co^{60} Heat Source
10 kw Cont. #1	27,300,000	5,500,000
Cont. #2	27,300,000	5,500,000
Cont. #3	27,300,000	5,500,000
Cont. #4	27,300,000	5,500,000
8 hr. #1	27,300,000	5,500,000
8 hr. #2	27,300,000	5,500,000
1 hr.	27,300,000	5,500,000

The system voltage, frequency, and generator costs have a minimal impact on the overall costs. Costs are based on continuous operation. For eight hours or less operations, there is no decrease in capital costs. The isotopic heat must be dissipated to the atmosphere when electric power is not being generated. Therefore, fuel is not saved when electric power is not being produced.

3.2 Life Cycle Cost (1977 Dollars)

The life cycle cost (LCC) formula applicable to this system is:

LCC = AC + FC + OMC

where AC = Acquisition Cost (see Section 3.1)

FC = Total Fuel Cost Over System Lifetime (see Section 3.6)

OMC = Operation and Maintenance Cost Over System Lifetime (see Section 3.15)

A. Pu^{238} Heat Source

Requirement	LCC (1977)	LCC/yr (1977)
10 kw Cont. #1	27,950,000	1,300,000
Cont. #2	27,950,000	1,300,000
Cont. #3	27,950,000	1,300,000
Cont. #4	27,950,000	1,300,000
8 hr. #1	27,950,000	1,300,000
8 hr. #2	27,950,000	1,300,000
1 hr.	27,950,000	1,300,000

B. Co^{60} Heat Source

Requirement	LCC (1977)	LCC/yr (1977)
10 kw Cont. #1	11,870,000	593,500
Cont. #2	11,870,000	593,500
Cont. #3	11,870,000	593,500
Cont. #4	11,870,000	593,500
8 hr. #1	11,870,000	593,500
8 hr. #2	11,870,000	593,500
1 hr.	11,870,000	593,500

The life cycle cost is based upon refurbishing the power system every five years. For the Pu^{238} radioisotope power system, refueling would not be required over its twenty-year life. For the Co^{60} radioisotope power system, refueling would be required every five years.

3.3 Lifetime (Years)

Requirement	1977
10 kw Cont. #1	20
Cont. #2	20
Cont. #3	20
Cont. #4	20
8 hr. #1	20
8 hr. #2	20
1 hr.	20

3.4 Volume/Size

Requirement	Area ft^2	Area m^2
10 kw Cont. #1	60	5.52
Cont. #2	60	5.52
Cont. #3	60	5.52
Cont. #4	60	5.52
8 hr. #1	60	5.52
8 hr. #2	60	5.52
1 hr.	60	5.52

Self-contained units can be designed to fit into a compact cylindrical module on the order of 4 feet by 15 feet for the Pu^{238} 10 KW_e system.

The Co^{60} 10 KW_e system would be larger in diameter as additional shielding is required for this unit since Co^{60} is a gamma emitter and Pu^{238} is an alpha emitter.

3.5 **Weight**

The weight of this power system should not exceed 16,000 pounds.

3.6 **Fuel**

The Pu^{238} radioistope heat source has a half life of 86.4 years. The 10 KW_e system fueled with Pu^{238} would not have to be refueled during the twenty-year life of the system.

The Co^{60} radioisotope heat source has a half life of 5.3 years. The 10 KW_e system fueled with Co^{60} would have to be refueled every five years during the twenty-year life of the system.

The cost of Pu^{238} fuel is included in the capital cost of the Pu^{238} 10 KW_e system. The cost of initial Co^{60} fuel for the Co^{60} 10 KW_e system is included in the capital cost of the system. The cost of the Co^{60} fuel at each five-year refueling intervals is $1,430,000.

Alternate Fuels

Alternate radioisotopes can be used as a heat source. The isotopes selected for the study are only typical of ones in general use.

Fuel Availability

Plutonium 238 is produced in small quantities as a by-product in the operation or power reactors. Currently, the only reactors in which Pu^{238} is

produced, on a large scale, are the Savannah Production Reactors. The best estimate of the availability of Pu^{238} to the year 1980 is 450 KW_t from commercial sources. The capability for fuel from production of Plutonium 238 heat sources is presently centered at Mound Laboratory and Los Alamos Scientific Laboratory. Both of these laboratories have limited production capability. Any future large requirements will necessitate the use of additional facilities, either governmental or private.

Cobalt 60 is produced by deliberate irradiation of natural Cobalt 59. Substantial quantities have been produced in reactors, like the General Electric Test Reactor (GETR), and as a by-product of the operation of the Savannah River Production Reactors. Projected availability by the year 1980 is 1200 KW_t. This production could be increased by a factor of five.

3.7 Environmental Constraints

The environmental constraints of the power system are indicated in the following tabulation:

X amount of uncontrolled emission

Y Amount of pollution which would be emitted with no controls

Z Degree of difficulty in meeting more strict regulations

Key: blank - none

0 - minor

◐ - moderate

● - major

Emissions	X	Y	Z
Thermal Discharge (a)	●	-	-
Thermal Discharge (b)	-	-	-
Air Pollution			
CO	-	-	-
HC	-	-	-
NO_x	-	-	-
SO_x	-	-	-
Particulates	-	-	-
Noise	-	-	-
Solid Waste	-	-	-
Chemical Waste	-	-	-
Radioactive Waste	-	-	-

Notes: (a) system is air or water cooled; heat rejected directly to atmosphere.

(b) system is water cooled; heat rejected to body of water or cooling tower. Water source and/or make-up required.

3.8 Location Constraints

The locational limitations of the power system, and the degree of difficulty in overcoming these limitations are indicated in the following tabulation.

— - no difficulty

O - minor difficulty

◐ - major difficulty

● - overriding limitation

LOCATION RESTRAINT	
Water required for cooling	-
Water required for process	-
Manning required during operation	-
Fuel deliveries required	-
Adequate solar insolation required	-
Adequate wind speed required	-
Isolation from population required	●
Electricity required for charging	-

3.9 Operational Constraints

The tabulated operating characteristics are applicable to the power system as indicated.

– – Characteristic not observed in system operation

O – Characteristic has minor effect on system performance

◐ – Characteristic has moderate effect on system performance

● – Characteristic has major effect on system performance

Operational Restraint	
Efficiency reduction at part load	O
Part load capability limitation	O
Dependence on solar insolation	–
Dependence on wind consistency	–
Overload capacity limitations	◐
Delayed response to rapid load changes	O
Life reduction from frequent rapid load changes	O

3.10 System Efficiency

Requirement	1980
10 kw Cont. #1	28%
Cont. #2	28
Cont. #3	28
Cont. #4	28
8 hr. #1	28
8 hr. #2	28
1 hr.	28

3.11 Type of System

Requirement	Mobile	Trans-portable	Fixed
10 kw Cont. #1		X	
Cont. #2		X	
Cont. #3		X	
Cont. #4		X	
8 hr. #1		X	
8 hr. #2		X	
1 hr.		X	

The system is transportable for installation at a site. The modular system can be removed and used at other sites. The system is transportable by truck, train, ship, or aircraft as a single sealed unit.

3.12 Start-up/Shut-down Times

Requirement	Start-up	Shut-down
10 kw Cont. #1	1 hr.	1 hr.
Cont. #2	1 hr.	1 hr.
Cont. #3	1 hr.	1 hr.
Cont. #4	1 hr.	1 hr.
8 hr. #1	1 hr.	1 hr.
8 hr. #2	1 hr.	1 hr.
1 hr.	1 hr.	1 hr.

3.13 Growth Potential

The power system is self-contained and is not modular. As a result, incremental power increases must be made in 10 kw steps.

3.14 Reliability

The tabulated conditions exist in the power system to the extent indicated.

— - Condition does not exist in system

O - Condition exists, but its extent is sufficiently minor as to have minimal effect on system performance or reliability

◐ - Condition exists, and its extent is sufficient to have a moderate effect on system performance or reliability

● - Condition exists and is a governing factor in determining system performance and reliability.

Conditions	
Numerous moving parts	O
High temperature operation	O
High stress levels	O
High radiation level	O
Corrosive attack	-
Thermal cycling	O
Non-modular design	●
Solar insolation required	-
Wind required	-

3.15 Maintenance and Operation

Requirement	Cost Per Year	Overhaul Duration (wks/yr)	Personnel Required Continuously
10 kw Cont. #1	32,500	NA	No
Cont. #2	32,500	NA	No
Cont. #3	32,500	NA	No
Cont. #4	32,500	NA	No
8 hr. #1	32,500	NA	No
8 hr. #2	32,500	NA	No
1 hr.	32,500	NA	No

Every five years, the power system must be removed from the site and sent to a facility for refueling and overhauling. Maintenance of the power system cannot be performed at the site.

3.16 Other Energy Production

Requirement	Btu/hr	kw thermal
10 kw Cont. #1	52,7000	15.4
Cont. #2	52,7000	15.4
Cont. #3	52,7000	15.4
Cont. #4	52,7000	15.4
8 hr. #1	52,7000	15.4
8 hr. #2	52,7000	15.4
1 hr.	52,7000	15.4

The temperature of the waste heat is suitable for the production of low temperature hot water only.

3.17 Availability of Raw Building Materials

Raw building materials are readily available for this type of power system.

3.18 Development

Development Program Cost and Duration

Requirement	Cost (1977 Dollars)	Time (Years)
10 kw Cont. #1	30,000,000	3
Cont. #2	30,000,000	3
Cont. #3	30,000,000	3
Cont. #4	30,000,000	3
8 hr. #1	30,000,000	3
8 hr. #2	30,000,000	3
1 hr.	30,000,000	3

Plutonium 238 and Cobalt 60 heat sources have been developed for the space program. Ten KW_e Brayton cycle power systems have also been developed. The costs presented above represent product development costs for engineering and prototype testing.

4.0 References

1. 719122, IECEC, "Radioisotopes - Famine or Feast - A Review of Availability," by James C. Graf and Paul E. Brown, Space Division, General Electric Co.

2. 719103, IECEC, "Large Cobalt 60 Heat Source Program," by J. W. Sadler and G. H. Parker, Astronuclear Laboratory, Westinghouse Electric Corporation

3. 729085, IECEC, "Isotope Brayton Electric Power System for 500 to 2500 Watt Range," by R. Macosko, G. J. Barna, H. Block, and B. Ingle, NASA

4. Telecon from R. Reyer, Burns and Roe, to D. R. Roberts, Westinghouse Advanced Power, dated March 4, 1977

5. Telecon from R. Reyer, Burns and Roe, to D. R. Roberts, Westinghouse Advanced Power, dated March 14, 1977

6. Telecon from R. Reyer, Burns and Roe, to G. Story, U. S. Army, Fort Belvoir

SECTION XVII

STEAM TURBINE GENERATOR (SOLAR)

1.0 SYSTEM DESCRIPTION

1.1 System Identification

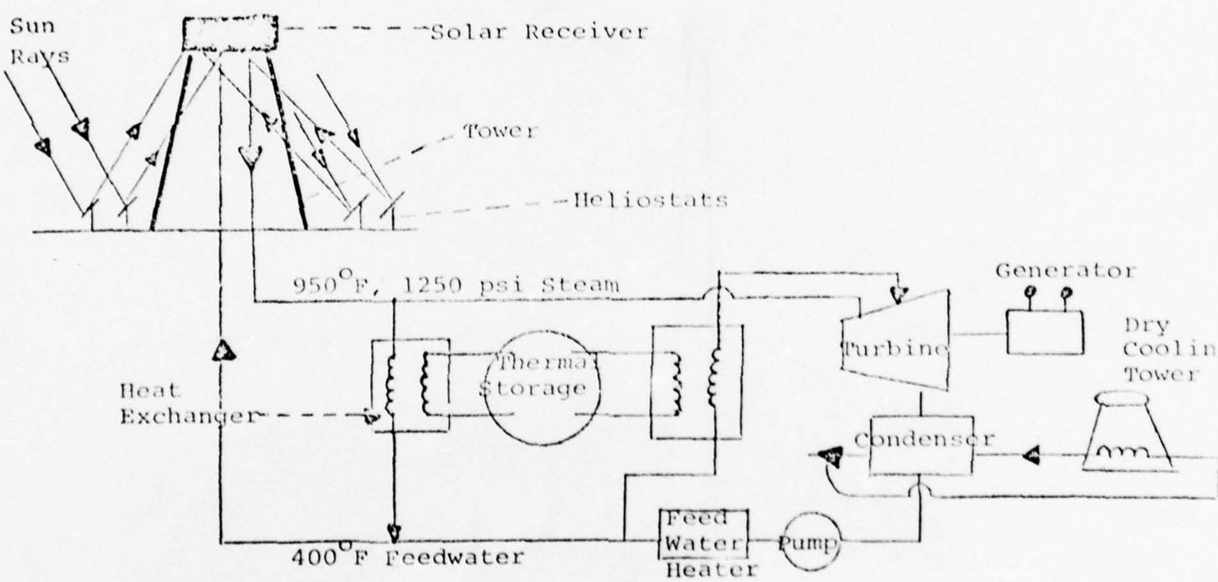
Fuel Converter - Solar Receiver

Energy Converter Cycle - Steam Turbine/Rankine Cycle

Fuel - Solar

Working Fluid - Water

1.2 System Definition



The major components of this system consist of the tower, solar receiver, heliostats, thermal storage system, steam turbine generator, condenser and cooling water system and other auxiliary systems. The plant is stationary and requires a large land area for a 50 MWe plant. The plant consists of the following major structures:

A. 1500 Foot Power Tower including solar receiver

B. Field of reflectors of solar energy (heliostats)

C. Thermal Storage Tanks and Structures

D. Turbine Generator Building

E. Cooling Towers and Circulating Water Pumphouses

F. Control and Auxiliary Buildings

This type of system must be constructed on a fixed site. It cannot be purchased as a prepackaged system. A significant engineering effort is required to coordinate the system engineering, design and construction for each site.

1.3 Physical Description

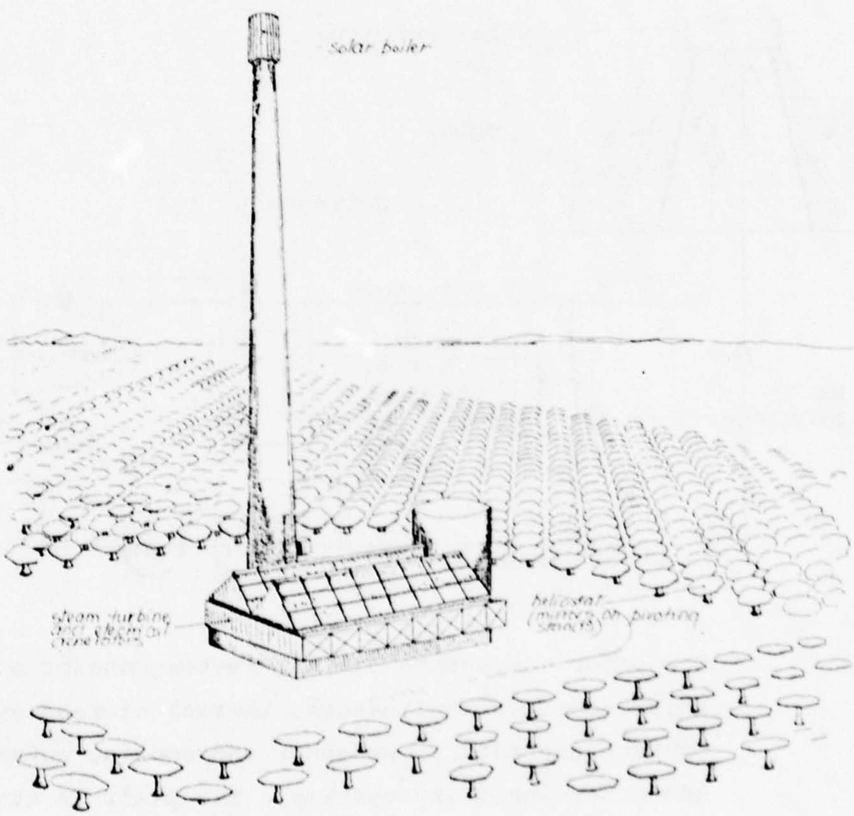


Figure 22. McDonnel Douglas Corp. conceptual design of a central-tower solar steam-electric power plant

2.0 LIST OF REQUIREMENTS AND TIME FRAMES

This power system is applicable to the following electrical power requirements as marked. The first date listed indicates the earliest time when the system will be available for purpose. Later dates indicate the point in time when significant improvements are expected.

	ELECTRICAL POWER REQUIREMENTS		1990
50 Mw	Continuous	(60 Hz - 3 ø - 13.8 kV)	X
	1-hour	(60 Hz - 3 ø - 13.8 kV)	X
10 MW	Continuous	(60 Hz - 3 ø - 4160 V)	X
	8 - hour	(60 Hz - 3 ø - 4160 V)	X
	1 - hour	(60 Hz - 3 ø - 4160 V)	X
750 kw	Continuous	(60 Hz - 3 ø - 4160 V)	N/A*
250 kw	Continuous	(60 Hz - 3 ø - 480 V)	N/A
50 kw	Continuous	(60 Hz - 3 ø - 480 V)	N/A
	8 - hour	(60 Hz - 3 ø - 480 V)	N/A
	1 - hour	(60 Hz - 3 ø - 480 V)	N/A
10 kw	Continuous #1	(DC - 28 V)	N/A
	Continuous #2	(60 Hz - 3 ø - 240 V)	N/A
	Continuous #3	(60 Hz - 1 ø - 240 V)	N/A
	Continuous #4	(60 Hz - 1 ø - 120 V)	N/A
	8 - hour #1	(DC - 28 V)	N/A
	8 - hour #2	(60 Hz - 3 ø - 240 V)	N/A
	1 - hour	(60 Hz - 3 ø - 240 V)	N/A

*Power requirements below 10 Mw were not considered since development of this technology by ERDA is only being considered for plants 10 Mw and above.

3.0 PARAMETERS

3.1 Acquisition Cost (1977 Dollars)

Requirement	1990
50 Mw Cont.	168,900,000
1 hr.	59,220,000
10 Mw Cont.	46,520,000
8 hr.	34,400,000
1 hr	32,470,000

Acquisition Cost Breakdown

A. Continuous Operation

	50 Mw	10 Mw
Heliostat Collectors	72,400,000	14,480,000
Receiver, Power, Piping	26,200,000	5,240,000
Energy Conversion System	14,200,000	6,400,000
Thermal Storage	13,900,000	2,800,000
Engineering and Other	14,800,000	10,000,000
Contingency @ 20%	27,400,000	7,600,000
	168,900,000	46,520,000

B. 8 Hours or Less Operation

	10 Mw
Heliostat Collectors	7,000,000
Receiver, Tower & Piping	5,240,000
Energy Conversion System	6,400,000
Engineering and Other Costs	10,000,000
Contingency @ 20%	5,700,000
	34,400,000

C. 1 Hour or Less Operation

	50 Mw	10 Mw
Heliostat Collectors	10,050,000	5,430,000
Receiver, Tower & Piping	10,300,000	5,240,000
Energy Conversion System	14,200,000	6,400,000
Engineering and Other Costs	14,800,000	10,000,000
Contingency @ 20%	9,870,000	5,400,000
	59,220,000	32,470,000

Acquisition costs are based on a site in Southern California

3.2 Life Cycle Cost (1977 Dollars)

The life cycle cost (LCC) formula applicable to this system is:

LCC = AC + OMC

where AC = Acquisition Cost (see Section 3.1)

OMC = Operation and Maintenance Cost over System Lifetime (see Section 3.15)

Requirement	LCC (1990)	LCC/yr (1990)
50 Mw Cont.	279,900,000	9,330,000
1 hr.	148,050,000	4,930,000
10 Mw Cont.	116,400,000	3,880,000
8 hr.	86,000,000	2,870,000
1 hr.	81,200,000	2,705,000

3.3 Lifetime (Years)

Requirement	1990
50 Mw Cont.	30
1 hr.	30
10 Mw Cont.	30
8 hr.	30
1 hr	30

3.4 Volume/Size

Requirement	Approximate Land Area Required	
	sq. miles	sq. kilometers
50 Mw Cont.	2.5	6.4
1 hr.	.3	.76
10 Mw Cont.	.5	1.3
8 hr.	.16	.42
1 hr.	.06	.156

3.5 Weight

Weight is not a relevant parameter for this type of system. Plant cannot be air lifted to provide ground power to remote sites. Plant must be constructed at a fixed site.

3.6 Fuel

Plant performance is determined by that rate and type of solar radiation that would be received by the collector and concentrated on the receiver. No fuel is used other than solar radiation.

To determine the actual plant output for each site, a solar model must be developed. Approximate variations in solar radiation throughout the United States are given in Appendix A. For the continuous use plant with 18 hours storage, the load factor possible is greater than .70 for a southwestern site. For the 8 hours or less use for the plant with no thermal storage, the load factor possible is .39. To achieve a high availability, a three hour thermal storage time for the one hour power requirement has been assumed.

3.7 Environmental Constraints

The environmental constraints of the power system are indicated in the following tabulation:

X amount of uncontrolled emission

Y Amount of pollution which would be emitted with no controls

Z Degree of difficulty in meeting more strict regulations

Key: blank - none

0 - minor

◐ - moderate

● - major

Emissions	X	Y	Z
Thermal Discharge (a)	-	-	-
Thermal Discharge (b)	●	●	●
Air Pollution			
CO	-	-	-
HC	-	-	-
NO_x	-	-	-
SO_x	-	-	-
Particulates	-	-	-
Noise	0	0	◐
Solid Waste	-	-	-
Chemical Waste	0	-	0
Radioactive Waste	-	-	-

Notes: (a) system is air or water cooled; heat rejected directly to atmosphere.
(b) system is water cooled; heat rejected to body of water or cooling tower. Water source and/or make-up required.

3.8 Location Constraints

The locational limitations of the power system, and the degree of difficulty in overcoming these limitations are indicated in the following tabulation.

— - no difficulty

O - minor difficulty

◐ - major difficulty

● - overriding limitation

LOCATION RESTRAINT	
Water required for cooling	◐
Water required for process	◐
Manning required during operation	●
Fuel deliveries required	-
Adequate solar insolation required	●
Adequate wind speed required	-
Isolation from population required	-
Electricity required for charging	-

3.9 Operational Constraints

The tabulated operating characteristics are applicable to the power system as indicated.

— - Characteristic not observed in system operation

O - Characteristic has minor effect on system performance

◓ - Characteristic has moderate effect on system performance

● - Characteristic has major effect on system performance

Operational Restraint	
Efficiency reduction at part load	◓
Part load capability limitation	◓
Dependence on solar insolation	●
Dependence on wind consistency	-
Overload capacity limitations	◓
Delayed response to rapid load changes	◓
Life reduction from frequent rapid load changes	◓

3.10 System Efficiency

Requirement	1990
50 Mw Cont.	17%
1 hr.	17
10 Mw Cont.	15
8 hr.	15
1 hr.	15

3.11 Type of System

Requirement	Mobile	Trans-portable	Fixed	Construction Time (years)
50 Mw Cont.			x	4
1 hr.			x	4
10 Mw Cont.			x	4
8 hr.			x	4
1 hr			x	4

The system must be constructed at a fixed site. Separate collector modules, steam turbine generators, solar receiver, cooling tower and interconnecting piping, wiring, control panels, etc. must be assembled at the site. Buildings and foundation structures to house the equipment must be constructed on site.

3.12 Start-up/Shut-down Time

Requirement	Start-up*	Shut-down
50 Mw Cont.	8 hr.	8 hr.
1 hr.	8 hr.	8 hr.
10 Mw Cont.	4 hr.	4 hr.
8 hr.	4 hr.	4 hr.
1 hr.	4 hr.	4 hr.

*Assuming cold start

3.13 Growth Potential

This type of power plant is non-modular by nature with the result that growth in capacity can be achieved only by adding plant equipment. If growth is planned from the beginning, equipment can be oversized for future additional capacity.

3.14 Reliability

The tabulated conditions exist in the power system to the extent indicated.

— - Condition does not exist in system

O - Condition exists, but its extent is sufficiently minor as to have minimal effect on system performance or reliability

◐ - Condition exists, and its extent is sufficient to have a moderate effect on system performance or reliability

● - Condition exists and is a governing factor in determining system performance and reliability.

Conditions	
Numerous moving parts	●
High temperature operation	O
High stress levels	O
High radiation level	-
Corrosive attack	O
Thermal cycling	◐
Non-modular design	●
Solar insolation required	●
Wind required	-

3.15 Maintenance and Operation

Requirement	Cost Per Year	Overhaul Duration (wks/yr)	Personnel Required Continuously
50 Mw Cont.	3,700,000	Not Known	yes
1 hr.	2,900,000	Not known	yes
10 Mw Cont.	2,330,000	Not known	yes
8 hr.	1,720,000	Not known	yes
1 hr	1,630,000	Not known	yes

Operation and Maintenance Requirements:

Maintenance costs are higher than for conventional power plants due to the large number of collectors (heliostats) utilized in this plant. These collectors must be cleaned, aligned and serviced on a periodic basis.

3.16 Other Energy Production

Requirement	10^6 Btu/hr	10^3 kw thermal
50 Mw Cont.	199	58.2
1 hr.	199	58.2
10 Mw Cont.	116	34.0
8 hr.	116	34.0
1 hr.	116	34.0

For a power plant of this type, thermal energy is discharged to the environment as low temperature condenser heat rejection to a body of water or to the atmosphere via wet or dry cooling towers. The electrical power output of the plant is maximized by making the temperatures of the thermal discharges as low as practicable. Temperatures would be suitable for the production of low pressure hot water only.

If more thermal energy is needed, there are other options available, all of which would reduce the electrical output of the power plant. Thermal energy can be made available in the form of hot water or steam over a wide range of conditions. However, the higher the temperature of the steam or hot water for a given amount of thermal energy, the lower the electrical output.

3.17 Availability of Raw Building Materials

Raw building materials are readily available for this type of power plant.

3.18 Development

A. Development Program Cost and Duration

Requirement	Cost (1977 Dollars)	Time (Years)
50 Mw Cont.	1,130,000,000	12
1 hr.	1,130,000,000	12
10 Mw Cont.	1,130,000,000	12
8 hr.	1,130,000,000	12
1 hr	1,130,000,000	12

Presently ERDA is funding the development of this type of power plant with an expected commercialization date in the 1990's.

Since this technology is not proven, there is an element of risk that a viable commercial plant can be developed.

4.0 References

(1) Solar Thermal Electric Power Plants: Their Performance Characteristics and Total Social Costs, R. S. Caputo, V. C. Truscello, Jet Propulsion Laboratory, Pasadena, California, 76213 IECEC 1976 Proceedings

(2) Telecon, R. Reyer, Burns and Roe, R. S. Caputo, Jet Propulsion Laboratory dated March 22, 1977.

(3) ERDA Program Opportunity Notice (PON), Central Receiver Solar Power 10 Megawatt Electric Pilot Plant Project Site Selections dated July 9, 1976.

(4) Solar Position Paper, Prepared as part of the Goldstone Energy System Study by Burns and Roe, Inc., for the Jet Propulsion Laboratory dated November 1975.

SECTION VIII

ORGANIC VAPOR TURBINE GENERATOR (SOLAR)

1.0 SYSTEM DESCRIPTION

1.1 System Identification

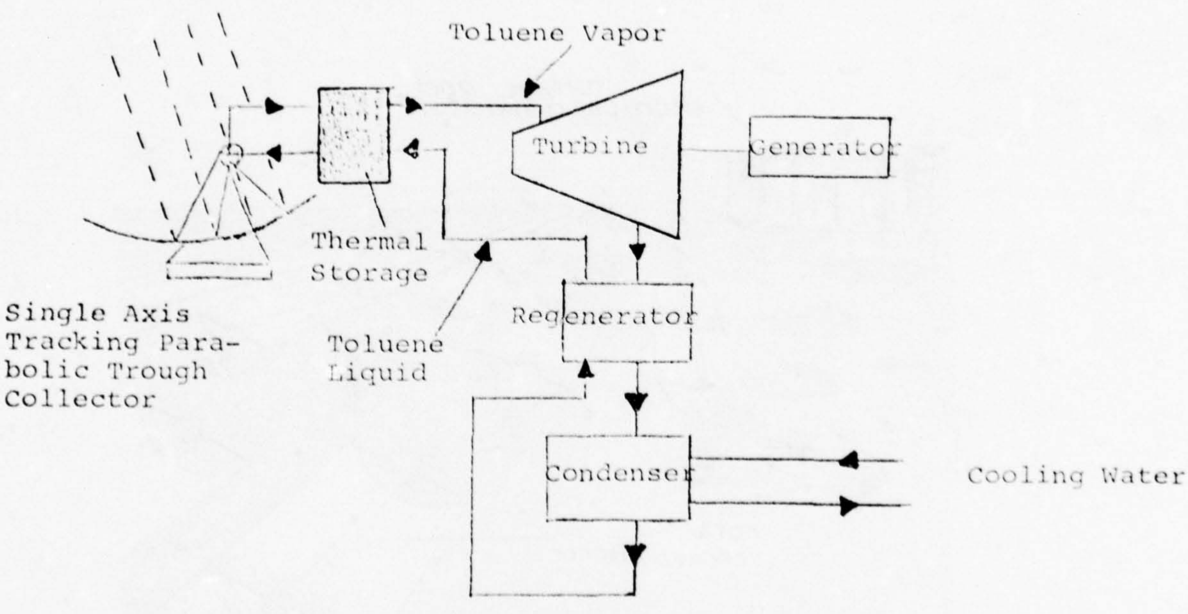
Fuel Converter: Single axis parabolic trough collector.

Energy Converter Cycle: Organic vapor turbine/Rankine cycle.

Fuel: Solar.

Working Fluid: Organic (toluene)

1.2 System Definition



The major components of this plant consist of parabolic trough collectors, thermal storage tanks, turbine generator, regenerator, condenser, and cooling water system. For a southwest site, the annual electric output is approximately .036 KW_e per square meter of collector area.

The plant is stationary and consists of the following major structures:

a. Field of solar parabolic trough collectors

b. Turbine generator building and control room

c. Cooling tower and cooling water pumps

d. High temperature storage area

This type of system must be erected on a fixed site. It cannot be purchased as a prepackaged system. A significant engineering effort is required to coordinate the system design and erection for each site.

1.3 Physical Description

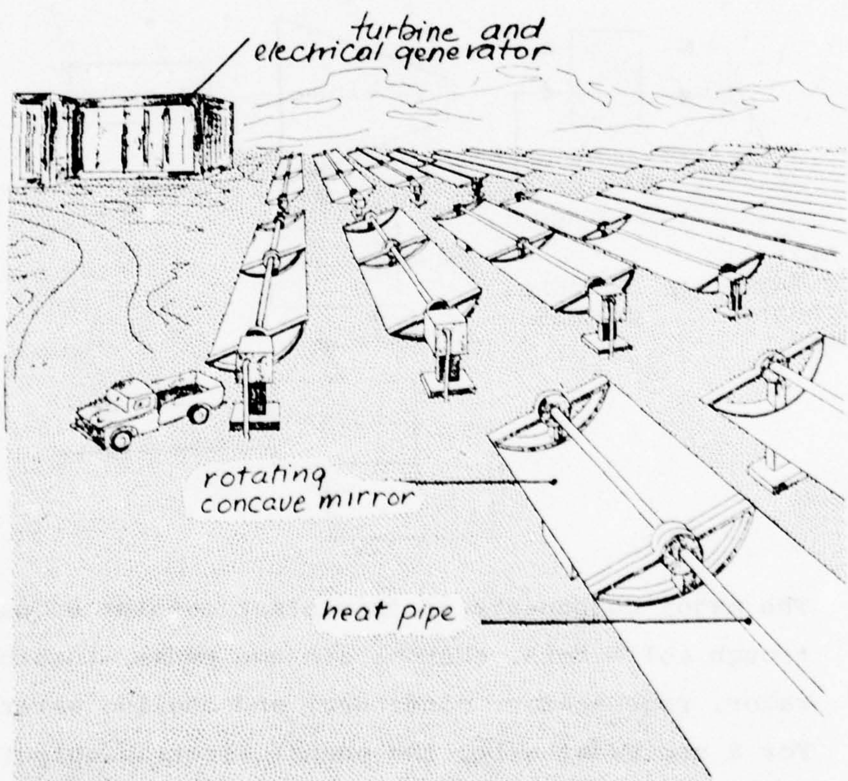


Figure 23. Honeywell Inc. concept of parabolic trough solar collectors which could be used with an organic vapor turbine-generator system.

2.0 LIST OF REQUIREMENTS AND TIME FRAMES

This power system is applicable to the following electrical power requirements as marked. The first date listed indicates the earliest time when the system will be available for purchase. Later dates indicate the point in time when significant improvements are expected.

	ELECTRICAL POWER REQUIREMENTS	1980
50 Mw	Continuous (60 Hz - 3 ø - 13.8 kV)	N/A*
	1-hour (60 Hz - 3 ø - 13.8 kV)	N/A
10 MW	Continuous (60 Hz - 3 ø - 4160 V)	N/A
	8 - hour (60 Hz - 3 ø - 4160 V)	N/A
	1 - hour (60 Hz - 3 ø - 4160 V)	N/A
750 kw	Continuous (60 Hz - 3 ø - 4160 V)	X
250 kw	Continuous (60 Hz - 3 ø - 480 V)	X
50 kw	Continuous (60 Hz - 3 ø - 480 V)	X
	8 - hour (60 Hz - 3 ø - 480 V)	X
	1 - hour (60 Hz - 3 ø - 480 V)	X
10 kw	Continuous #1 (DC - 28 V)	X
	Continuous #2 (60 Hz - 3 ø - 240 V)	X
	Continuous #3 (60 Hz - 1 ø - 240 V)	X
	Continuous #4 (60 Hz - 1 ø - 120 V)	X
	8 - hour #1 (DC - 28 V)	X
	8 - hour #2 (60 Hz - 3 ø - 240 V)	X
	1 - hour (60 Hz - 3 ø - 240 V)	X

*Power levels above 750 kw are not being considered because a 600 kw organic Rankine cycle turbine is the highest power level presently being developed by ERDA.

3.0 PARAMETERS

3.1 Acquisition Cost (1977 Dollars)

Requirement	1980
750 kw Cont.	6,015,000
250 kw Cont.	2,616,000
50 kw Cont.	1,306,000
8 hr.	1,146,000
1 hr.	1,067,000
10 kw Cont. #1	830,000
Cont. #2	830,000
Cont. #3	830,000
Cont. #4	830,000
8 hr. #1	798,000
8 hr. #2	798,000
1 hr.	784,000

Acquisition Cost Breakdown

A. Continuous Operation

	10 KWe	50 KWe	250 KWe	750 KWe
Solar Collectors	37,000	188,000	943,000	2,830,000
T-G Organic Rankine Unit	43,000	97,000	217,000	375,000
Energy Storage	11,000	54,000	270,000	810,000
Engineering and Construction Management	600,000	750,000	750,000	1,000,000
Contingency at 20%	138,000	217,000	436,000	1,000,000
Total Costs	830,000	1,306,000	2,616,000	6,015,000

B. Eight Hours or Less

	10 KWe	50 KWe	250 KWe	750 KWe
Solar Collectors	18,000	90,000	449,000	1,347,000
T-G Organic Rankine Unit	43,000	96,000	217,000	375,000
Energy Storage	4,000	18,000	90,000	270,000
Engineering and Construction Management	600,000	750,000	750,000	1,000,000
Contingency at 20%	133,000	191,000	301,000	600,000
Total Costs	798,000	1,146,000	1,807,000	3,590,000

C. One-Hour Operation

	10 KWe	50 KWe	250 KWe	750 KWe
Solar Collectors	7,000	33,000	168,000	505,000
T-G Organic Rankine Unit	43,000	96,000	217,000	375,000
Energy Storage	4,000	9,000	45,000	135,000
Engineering and Construction Management	600,000	750,000	750,000	1,000,000
Contingency at 20%	133,000	178,000	268,000	403,000
Total Costs	784,000	1,067,000	1,606,000	2,418,000

The system voltage frequency and generator costs have a minimal impact on the overall costs.

Acquisition costs are based on a site in southern California with thermal storage for each power requirement as follows:

1. Continuous - 18 hours thermal storage
2. Eight hours or less - 6 hours thermal storage
3. One hour or less - 3 hours thermal storage

3.2 Life Cycle Cost (1977 Dollars)

The life cycle cost (LCC) formula applicable to this system is:

LCC = AC + OMC

where AC = Acquisition Cost (see Section 3.1)

OMC = Operation and Maintenance Cost Over System Lifetime (see Section 3.15)

Requirement	LCC (1980)	LCC/yr (1980)
750 kw Cont.	15,035,000	500,200
250 kw Cont.	6,530,000	217,700
50 kw Cont.	3,265,000	108,800
8 hr.	2,865,000	95,500
1 hr.	2,667,000	88,900
10 kw Cont. #1	2,075,000	69,200
Cont. #2	2,075,000	69,200
Cont. #3	2,075,000	69,200
Cont. #4	2,075,000	69,200
8 hr. #1	1,995,000	66,500
8 hr. #2	1,995,000	66,500
1 hr.	1,950,000	65,000

3.3 Lifetime (Years)

Requirement	1980
750 kw Cont.	30
250 kw Cont.	30
50 kw Cont.	30
8 hr.	30
1 hr.	30
10 kw Cont. #1	30
Cont. #2	30
Cont. #3	30
Cont. #4	30
8 hr. #1	30
8 hr. #2	30
1 hr.	30

3.4 Volume/Size

Requirement	Approximate Land Area Required for Solar Collectors	
	sq. ft.	sq. m.
750 kw Cont.	154,300	14,200
250 kw Cont.	51,300	4,700
50 kw Cont.	10,300	950
8 hr.	4,900	451
1 hr.	1,800	166
10 kw Cont. #1	2,053	190
Cont. #2	2,053	190
Cont. #3	2,053	190
Cont. #4	2,053	190
8 hr. #1	980	90
8 hr. #2	980	90
1 hr.	370	34

Plant Size	Size of Organic Rankine Cycle Turbine Generators
	Volume (ft^3)
10 KWe	150
50 KWe	180
250 KWe	700
750 KWe	2,000

3.5 Weight

Weight is not a relevant parameter for this type of system. The plant cannot be air lifted to provide ground power to remote sites. The plant must be erected at a fixed site.

3.6 Fuel

Plant performance is determined by the rate and type of solar radiation that would be received by the collector. No fuel is used other than solar radiation.

To determine the actual plant output for each site, a solar model must be developed. Approximate variations in plant output from the base site used for the system presented herein can be determined from the map of solar insolation of the United States, included in Appendix A.

For the continuous use plant with 18 hours' storage, the load factor possible is greater than .70 for a southwestern site. For the eight hours or less use for the plant with no thermal storage, the load factor possible is .39.

To achieve a high availability, a three-hour storage time for the one-hour power requirement has been assumed.

3.7 Environmental Constraints

The environmental constraints of the power system are indicated in the following tabulation:

X amount of uncontrolled emission

Y Amount of pollution which would be emitted with no controls

Z Degree of difficulty in meeting more strict regulations

Key: blank - none

0 - minor

◐ - moderate

● - major

Emissions	X	Y	Z
Thermal Discharge (a)	-	-	-
Thermal Discharge (b)	●	●	●
Air Pollution			
CO	-	-	-
HC	-	-	-
NO_x	-	-	-
SO_x	-	-	-
Particulates	-	-	-
Noise	0	0	◐
Solid Waste	-	-	-
Chemical Waste	0	-	0
Radioactive Waste	-	-	-

Notes: (a) system is air or water cooled; heat rejected directly to atmosphere.

(b) system is water cooled; heat rejected to body of water or cooling tower. Water source and/or make-up required.

3.8 Location Constraints

The locational limitations of the power system, and the degree of difficulty in overcoming these limitations are indicated in the following tabulation.

— - no difficulty

O - minor difficulty

◐ - major difficulty

● - overriding limitation

LOCATION RESTRAINT	
Water required for cooling	◐
Water required for process	-
Manning required during operation	O
Fuel deliveries required	-
Adequate solar insolation required	●
Adequate wind speed required	-
Isolation from population required	-
Electricity required for charging	-

3.9 Operational Constraints

The tabulated operating characteristics are applicable to the power system as indicated.

— - Characteristic not observed in system operation

O - Characteristic has minor effect on system performance

◐ - Characteristic has moderate effect on system performance

● - Characteristic has major effect on system performance

Operational Restraint	
Efficiency reduction at part load	-
Part load capability limitation	O
Dependence on solar insolation	●
Dependence on wind consistency	-
Overload capacity limitations	◐
Delayed response to rapid load changes	◐
Life reduction from frequent rapid load changes	-

3.10 System Efficiency

Requirement	1980
750 kw Cont.	14%
250 kw Cont.	12%
50 kw Cont.	11%
8 hr.	11%
1 hr.	11%
10 kw Cont. #1	8.5%
Cont. #2	8.5%
Cont. #3	8.5%
Cont. #4	8.5%
8 hr. #1	8.5%
8 hr. #2	8.5%
1 hr.	8.5%

3.11 Type of System

Requirement	Mobile	Trans-portable	Fixed
750 kw Cont.			X
250 kw Cont.			X
50 kw Cont.			X
8 hr.			X
1 hr.			X
10 kw Cont. #1			X
Cont. #2			X
Cont. #3			X
Cont. #4			X
8 hr. #1			X
8 hr. #2			X
1 hr.			X

The system is transportable in pieces for installation at a fixed site. Separate collector modules, organic Rankine cycle turbine generator module, cooling tower module, and interconnecting piping, wiring, control panels, etc. must be assembled at the site.

3.12 Start-up/Shut-down Times

Requirement	Start-up	Shut-down
750 kw Cont.	1 hr.	1 hr.
250 kw Cont.	1 hr.	1 hr.
50 kw Cont.	1 hr.	1 hr.
8 hr.	1 hr.	1 hr.
1 hr.	1 hr.	1 hr.
10 kw Cont. #1	1 hr.	1 hr.
Cont. #2	1 hr.	1 hr.
Cont. #3	1 hr.	1 hr.
Cont. #4	1 hr.	1 hr.
8 hr. #1	1 hr.	1 hr.
8 hr. #2	1 hr.	1 hr.
1 hr.	1 hr.	1 hr.

3.13 Growth Potential

The collector field is modular. Therefore, incremental increases in output are possible, providing the turbine-generator unit was selected with excess capacity.

3.14 Reliability

The tabulated conditions exist in the power system to the extent indicated.

— - Condition does not exist in system

O - Condition exists, but its extent is sufficiently minor as to have minimal effect on system performance or reliability

◐ - Condition exists, and its extent is sufficient to have a moderate effect on system performance or reliability

● - Condition exists and is a governing factor in determining system performance and reliability.

Conditions	
Numerous moving parts	0
High temperature operation	0
High stress levels	0
High radiation level	-
Corrosive attack	-
Thermal cycling	0
Non-modular design	-
Solar insolation required	●
Wind required	-

3.15 Maintenance and Operation

Requirement	Cost Per Year	Overhaul Duration (wks/yr)	Personnel Required Continuously
750 kw Cont.	300,600	2 weeks	Yes
250 kw Cont.	109,800	2 weeks	Yes
50 kw Cont.	65,300	2 weeks	No
8 hr.	57,300	2 weeks	No
1 hr.	53,300	2 weeks	No
10 kw Cont. #1	40,500	2 weeks	No
Cont. #2	40,500	2 weeks	No
Cont. #3	40,500	2 weeks	No
Cont. #4	40,500	2 weeks	No
8 hr. #1	40,000	2 weeks	No
8 hr. #2	40,000	2 weeks	No
1 hr.	38,600	2 weeks	No

Operation and Maintenance Requirements:

Maintenance costs are higher than for conventional power systems due to the large number of solar collectors utilized in this plant. These collectors must be cleaned, aligned, and serviced on a periodic basis. Organic Rankine cycle turbine must be completely refurbished every three to five years.

3.16 Other Energy Production

Requirement	Btu/hr	kw Thermal
750 kw Cont.	4,152,500	1,220
250 kw Cont.	1,621,200	475
50 kw Cont.	363,000	110
8 hr.	363,000	110
1 hr.	363,000	110
10 kw Cont. #1	100,000	30
Cont. #2	100,000	30
Cont. #3	100,000	30
Cont. #4	100,000	30
8 hr. #1	100,000	30
8 hr. #2	100,000	30
1 hr.	100,000	30

The temperature of the rejected heat is suitable for the production of low pressure hot water only.

3.17 Availability of Raw Building Materials

Raw building materials are readily available for this type of power plant.

3.18 Development

A. Development Program Cost and Duration

Requirement		Cost (1977 Dollars)	Time (Years)
750 kw	Cont.	5,000,000	3
250 kw	Cont.	5,000,000	3
50 kw	Cont.	5,000,000	3
	8 hr.	5,000,000	3
	1 hr.	5,000,000	3
10 kw	Cont. #1	5,000,000	3
	Cont. #2	5,000,000	3
	Cont. #3	5,000,000	3
	Cont. #4	5,000,000	3
	8 hr. #1	5,000,000	3
	8 hr. #2	5,000,000	3
	1 hr.	5,000,000	3

Development costs for the solar collectors for engineering and prototype testing would be approximately 3 million dollars.

Development costs for various size organic Rankine cycle units would be approximately 2 million dollars. Development time should be on the order of three years. Production time is on the order of one year.

4.0 References

1. Telecon dated 5/26/77 from R. Reyer to W. Adams, Sunstrand Corporation
2. "Solar Thermal Energy Conversion Program Summary," October, 1976, ERDA 76-159
3. Solar Position Paper No. 75-117, repared as part of the Goldstone Energy System Study by Burns and Roe, Inc., for the Jet Propulsion Laboratory
4. "An Initial Comparative Assessment of Orbital and Terrestrial Central Power Systems," 900-780, March, 1977, by R. Caputo, Jet Propulsion Laboratory

SECTION XIX

GAS TURBINE GENERATOR (SOLAR)

1.0 SYSTEM DESCRIPTION

1.1 System Identification

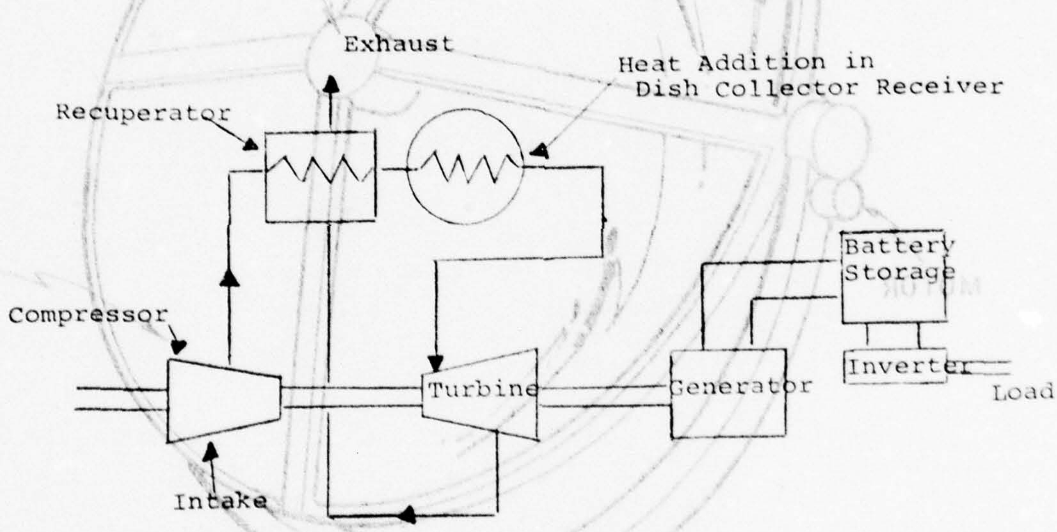
Fuel Converter: Tracking Dish Collector

Energy Converter Cycle: Gas Turbine/Open Brayton Cycle

Fuel: Solar

Working Fluid: Air

1.2 System Definition



The power generating part of the system is modular in construction. Each module consists of a dish collector with tracking mechanism and heat receiver, a thermal transfer loop, an open cycle gas turbine (including turbine, compressor and recuperator) and a generator. The battery storage, inverter, and associated controls are centralized and are connected to all of the modules. These modules are considered feasible in the power generation range of 10 KWe to 30 KWe. Many modules can be operated in parallel to produce high power levels.

1.3 Physical Description

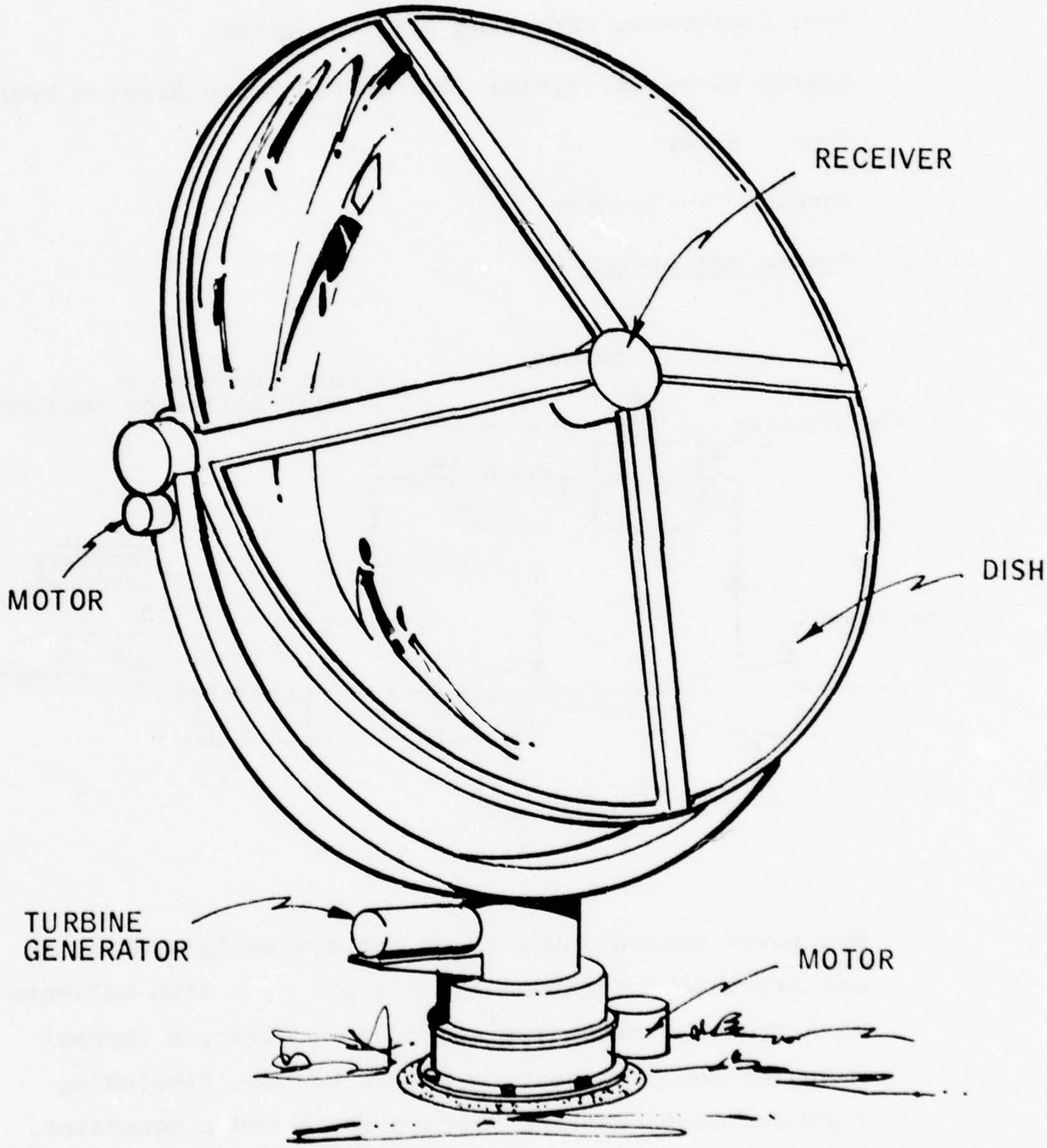


Figure 24. Artist's concept of individual solar-gas turbine power module by Honeywell, Inc.

2.0 LIST OF REQUIREMENTS AND TIME FRAMES

This power system is applicable to the following electrical power requirements as marked. The first date listed indicates the earliest time when the system will be available for purchase. Later dates indicate the point in time when significant improvements are expected.

ELECTRICAL POWER REQUIREMENTS

			1980
50 Mw	Continuous	(60 Hz - 3 ø - 13.8 kV)	X
	1-hour	(60 Hz - 3 ø - 13.8 kV)	X
10 MW	Continuous	(60 Hz - 3 ø - 4160 V)	X
	8 - hour	(60 Hz - 3 ø - 4160 V)	X
	1 - hour	(60 Hz - 3 ø - 4160 V)	X
750 kw	Continuous	(60 Hz - 3 ø - 4160 V)	X
250 kw	Continuous	(60 Hz - 3 ø - 480 V)	X
50 kw	Continuous	(60 Hz - 3 ø - 480 V)	X
	8 - hour	(60 Hz - 3 ø - 480 V)	X
	1 - hour	(60 Hz - 3 ø - 480 V)	X
10 kw	Continuous #1	(DC - 28 V)	X
	Continuous #2	(60 Hz - 3 ø - 240 V)	X
	Continuous #3	(60 Hz - 1 ø - 240 V)	X
	Continuous #4	(60 Hz - 1 ø - 120 V)	X
	8 - hour #1	(DC - 28 V)	X
	8 - hour #2	(60 Hz - 3 ø - 240 V)	X
	1 - hour	(60 Hz - 3 ø - 240 V)	X

3.0 PARAMETERS

3.1 Acquisition Cost (1977 Dollars)

Requirement	1980
50 Mw Cont.	346,000,000
1 hr.	39,000,000
10 Mw Cont.	68,300,000
8 hr.	20,300,000
1 hr.	7,900,000
750 kw Cont.	5,170,000
250 kw Cont.	1,740,000
50 kw Cont.	354,000
8 hr.	115,000
1 hr.	41,900
10 kw Cont. #1	60,900
Cont. #2	60,900
Cont. #3	60,900
Cont. #4	60,900
8 hr. #1	20,900
8 hr. #2	20,900
1 hr.	20,900

Acquisition Cost Breakdown

A. Continuous Operation

	10 KWe	50 KWe	250 KWe	750 KWe	10 MWe	50 MWe
Solar Collectors and Power Conversion Equipment	28,900	144,500	722,500	2,170,000	28,000,000	149,000,000
Battery Storage and Inverters	32,000	150,000	725,000	2,140,000	28,000,000	140,000,000
Contingency at 20%	---	59,000	289,000	860,000	11,400,000	59,800,000
TOTAL COSTS	60,900	354,000	1,740,000	5,170,000	68,300,000	346,800,000

B. Eight Hours or Less

	10 KWe	50 KWe	10 MWe
Solar Collectors and Power Conversion Equipment	14,400	73,000	14,400,000
Battery Storage and Inverters	6,500	23,000	2,500,000
Contingency at 20%	-	19,000	3,400,000
Total Costs	20,900	115,000	20,300,000

C. One Hour Operation

Plant Size	No. of 10 KWe Power Power Modules	Total Capital Cost
10 KWe	1	.0209
50 KWe	2	.0419
10 MWe	375	7.90
50 MWe	1875	39.30

The system voltage frequency and generator costs have a minimal impact on the overall costs.

3.2 Life Cycle Cost (1977 Dollars)

The life cycle cost (LCC) formula applicable to this system is:

LCC = AC + OMC

where AC = Acquisition Cost (See Section 3.1)

OMC = Operation and Maintenance Cost over System Lifetime (See Section 3.15)

Requirement	LCC 1980 Technology	LCC/YR
50 Mw Cont.	457,800,000	15,260,000
1 hr.	98,250,000	3,280,000
10 Mw Cont.	170,800,000	5,690,000
8 hr.	50,750,000	1,700,000
1 hr.	19,250,000	658,000
750 kw Cont.	12,920,000	430,000
250 kw Cont.	4,350,000	145,000
50 kw Cont.	885,000	29,500
8 hr.	288,000	9,600
1 hr.	104,500	3,500
10 kw Cont. #1	152,000	5,000
Cont. #2	152,000	5,000
Cont. #3	152,000	5,000
Cont. #4	152,000	5,000
8 hr. #1	51,900	1,730
8 hr. #2	51,900	1,730
1 hr.	51,900	1,730

3.3 Lifetime (Years)

Requirement	1980
50 Mw Cont.	30
1 hr.	30
10 Mw Cont.	30
8 hr.	30
1 hr.	30
750 kw Cont.	30
250 kw Cont.	30
50 kw Cont.	30
8 hr.	30
1 hr.	30
10 kw Cont. #1	30
Cont. #2	30
Cont. #3	30
Cont. #4	30
8 hr. #1	30
8 hr. #2	30
1 hr.	30

The lifetime projected for solar collectors is 30 years. However, refurbishing of parts for the collectors and Brayton Cycle turbine generator will be periodically necessary every three to five years. Lead acid batteries must be replaced every ten years.

3.4 Volume/Size

Requirement	Approximate Land Area Required	
	sq. ft.	sq. m.
50 Mw Cont.	8,650,000	804,000
1 hr.	1,080,000	100,000
10 Mw Cont.	1,730,000	160,000
8 hr.	577,000	54,000
1 hr.	216,000	20,000
750 kw Cont.	130,000	12,000
250 kw Cont.	43,200	4,000
50 kw Cont.	8,640	800
8 hr.	2,880	270
1 hr.	1,152	106
10 kw Cont. #1	1,728	160
Cont. #2	1,728	160
Cont. #3	1,728	160
Cont. #4	1,728	160
8 hr. #1	576	54
8 hr. #2	576	54
1 hr.	576	54

A self-contained 10 KWe module would consist of a 24 foot diameter collector 4 feet in depth with a 150 ft^3 volume power conversion system underneath the collector. Approximate land area requirements for this modular system, for different power requirements, are given above.

3.5 **Weight**

Weight of module is not known. Modules in pieces can be air lifted for assembly at a remote site.

3.6 **Fuel**

Plant performance is determined by the rate and type of solar radiation that would be received by the collector.

No fuel is used other than solar radiation.

To determine the actual plant output for each site, a solar model must be developed. Approximate variations in plant output from the base southwestern site used for the system presented herein can be determined from the map of solar insolation for the United States included in Appendix A. For the continuous use plant, with 18 hours battery storage, the load factor possible is .70 for a southwestern site.

To achieve a high availability, a three hour battery storage time for the 8 hours and one hour power requirement has been assumed.

3.7 Environmental Constraints

The environmental constraints of the power system are indicated in the following tabulation:

X amount of uncontrolled emission

Y Amount of pollution which would be emitted with no controls

Z Degree of difficulty in meeting more strict regulations

Key: blank - none

0 - minor

◐ - moderate

● - major

Emissions	X	Y	Z
Thermal Discharge (a)	●	-	-
Thermal Discharge (b)	-	-	-
Air Pollution			
CO	-	-	-
HC	-	-	-
NO_x	-	-	-
SO_x	-	-	-
Particulates	-	-	-
Noise	0	0	◐
Solid Waste	-	-	-
Chemical Waste	-	-	-
Radioactive Waste	-	-	-

Notes: (a) system is air or water cooled; heat rejected directly to atmosphere.
(b) system is water cooled; heat rejected to body of water or cooling tower. Water source and/or make-up required.

3.8 Location Constraints

The locational limitations of the power system, and the degree of difficulty in overcoming these limitations are indicated in the following tabulation.

— - no difficulty
O - minor difficulty
◐ - major difficulty
● - overriding limitation

LOCATION RESTRAINT	
Water required for cooling	-
Water required for process	-
Manning required during operation	O
Fuel deliveries required	-
Adequate solar insolation required	●
Adequate wind speed required	-
Isolation from population required	-
Electricity required for charging	-

3.9 Operational Constraints

The tabulated operating characteristics are applicable to the power system as indicated.

- – Characteristic not observed in system operation

O – Characteristic has minor effect on system performance

◓ – Characteristic has moderate effect on system performance

● – Characteristic has major effect on system performance

Operational Restraint	
Efficiency reduction at part load	–
Part load capability limitation	–
Dependence on solar insolation	●
Dependence on wind consistency	–
Overload capacity limitations	◓
Delayed response to rapid load changes	–
Life reduction from frequent rapid load changes	–

3.10 System Efficiency

Requirement		1980
50 Mw	Cont.	15%
	1 hr.	15%
10 Mw	Cont.	15%
	8 hr.	15%
	1 hr.	15%
750 kw	Cont.	15%
250 kw	Cont.	15%
50 kw	Cont.	15%
	8 hr.	15%
	1 hr.	15%
10 kw	Cont. #1	15%
	Cont. #2	15%
	Cont. #3	15%
	Cont. #4	15%
	8 hr. #1	15%
	8 hr. #2	15%
	1 hr.	15%

3.11 Type of System

Requirement	Mobile	Trans- portable	Fixed	Construction Time (years)
50 Mw Cont.			X	1
1 hr.			X	1
10 Mw Cont.			X	1
8 hr.			X	1
1 hr.			X	1
750 kw Cont.			X	1/2
250 kw Cont.			X	1/3
50 kw Cont.			X	1/10
8 hr.			X	1/10
1 hr.			X	1/10
10 kw Cont. #1			X	1/10
Cont. #2			X	1/10
Cont. #3			X	1/10
Cont. #4			X	1/10
8 hr. #1			X	1/10
8 hr. #2			X	1/10
1 hr.			X	1/10

The system is transportable in pieces for installation at a fixed site. The higher the power level the greater the number of 10 KWe modules required. Interconnecting wiring and control panels must be assembled at the site.

3.12 Start-up/Shut-down Time

Requirement		Start-up	Shut-down
50 Mw	Cont.	1 hr.	1 hr.
	1 hr.	1 hr.	1 hr.
10 Mw	Cont.	1 hr.	1 hr.
	8 hr.	1 hr.	1 hr.
	1 hr.	1 hr.	1 hr.
750 kw	Cont.	1 hr.	1 hr.
250 kw	Cont.	1 hr.	1 hr.
50 kw	Cont.	1 hr.	1 hr.
	8 hr.	1 hr.	1 hr.
	1 hr.	1 hr.	1 hr.
10 kw	Cont. #1	1 hr.	1 hr.
	Cont. #2	1 hr.	1 hr.
	Cont. #3	1 hr.	1 hr.
	Cont. #4	1 hr.	1 hr.
	8 hr. #1	1 hr.	1 hr.
	8 hr. #2	1 hr.	1 hr.
	1 hr.	1 hr.	1 hr.

3.13 Growth Potential

Incremental power increases can be readily achieved since the system is inherently modular.

3.14 Reliability

The tabulated conditions exist in the power system to the extent indicated.

— - Condition does not exist in system

O - Condition exists, but its extent is sufficiently minor as to have minimal effect on system performance or reliability

◐ - Condition exists, and its extent is sufficient to have a moderate effect on system performance or reliability

● - Condition exists and is a governing factor in determining system performance and reliability.

Conditions	
Numerous moving parts	O
High temperature operation	O
High stress levels	O
High radiation level	-
Corrosive attack	O
Thermal cycling	O
Non-modular design	-
Solar insolation required	●
Wind required	-

3.15 Maintenance and Operation

Requirement		Cost Per Year	Overhaul Duration (wks/yr)	Personnel Required Continuously
50 Mw	Cont.	3,700,000	Not Known	Yes
	1 hr.	1,970,000	Not Known	Yes
10 Mw	Cont.	3,400,000	Not Known	Yes
	8 hr.	1,015,000	Not Known	Yes
	1 hr.	395,000	Not Known	Yes
750 kw	Cont.	260,000	2 weeks	Yes
250 kw	Cont.	87,000	2 weeks	Yes
50 kw	Cont.	17,700	2 weeks	No
	8 hr.	9,600	2 weeks	No
	1 hr.	2,100	2 weeks	No
10 kw	Cont. #1	3,050	2 weeks	No
	Cont. #2	3,050	2 weeks	No
	Cont. #3	3,050	2 weeks	No
	Cont. #4	3,050	2 weeks	No
	8 hr. #1	1,033	2 weeks	No
	8 hr. #2	1,033	2 weeks	No
	1 hr.	1,033	2 weeks	No

Maintenance costs are higher than for conventional power systems due to the solar collectors which must be cleaned, aligned and serviced on a periodic basis. Overhaul of the Brayton cycle turbine generator is necessary every three to five years. Replacement storage batteries are necessary every 10 years.

3.16 Other Energy Production

Requirement	Btu/hr	kw Thermal
50 Mw Cont.	238,910,000	70,000
1 hr.	238,910,000	70,000
10 Mw Cont.	47,782,000	14,000
8 hr.	47,782	14,000
1 hr.	47,782	14,000
750 kw Cont.	3,584,000	1,050
250 kw Cont.	1,195,000	350
50 kw Cont.	239,000	70
8 hr.	239,000	70
1 hr.	239,000	70
10 kw Cont. #1	47,800	14
Cont. #2	47,800	14
Cont. #3	47,800	14
Cont. #4	47,800	14
8 hr. #1	47,800	14
8 hr. #2	47,800	14
1 hr.	47,800	14

For a power plant of this type, thermal energy is discharged to the environment as high temperature turbine exhaust gases leaving the recuperator. These exhaust gases can be utilized to provide energy for hot water or saturated steam.

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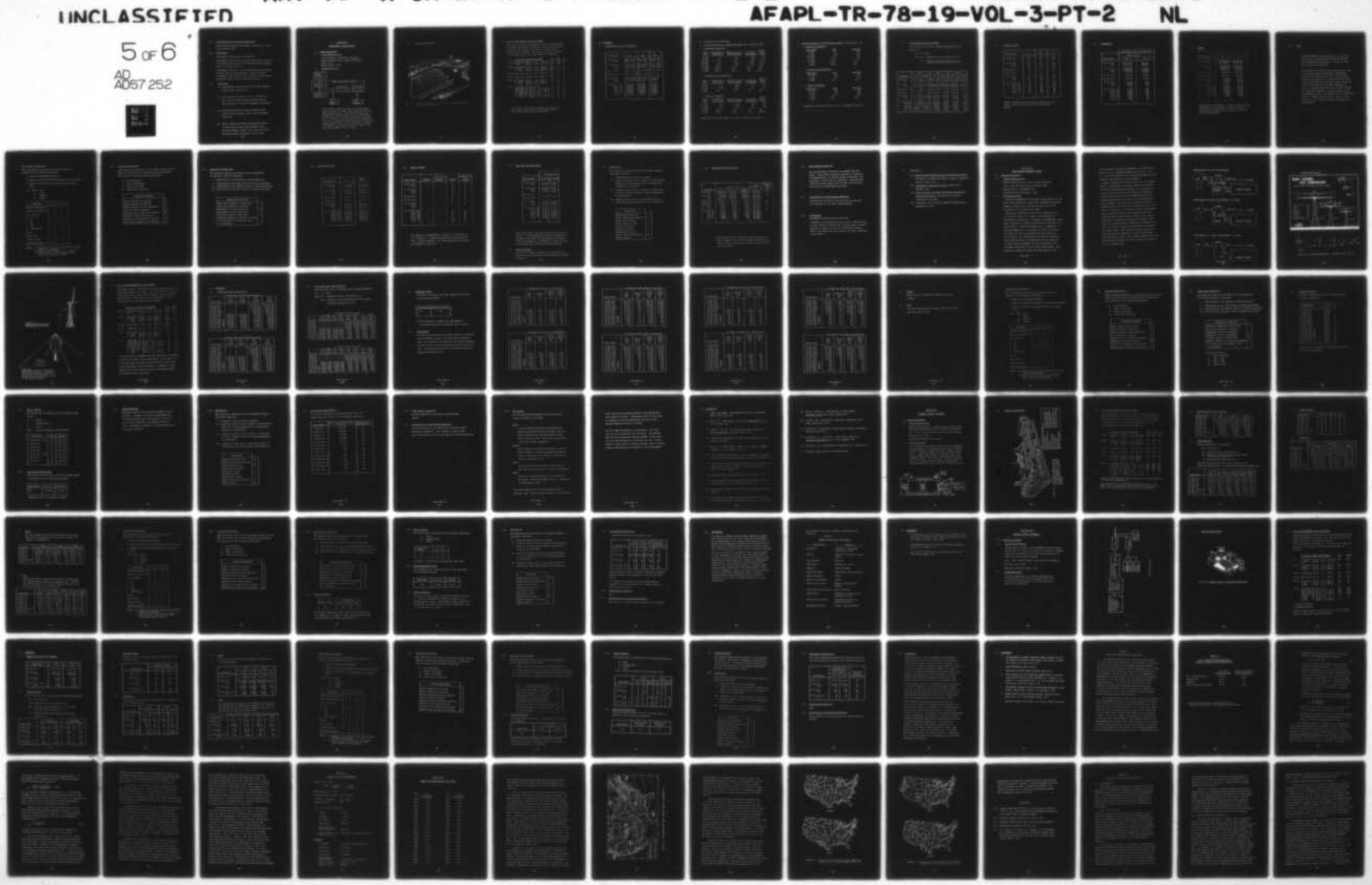
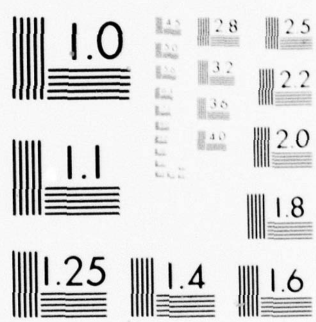




MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963-A

3.17 Availability of Raw Building Materials

Raw building materials are readily available for this type of power plant.

3.18 Development

Development Program Cost and Duration:

Development costs for the tracking dish solar collector for engineering and prototype testing would be approximately 3 million dollars.

Development costs for various size Brayton cycle power systems would be approximately 2 million dollars. Development time should be on the order of three years. Production time is on the order of one year.

4.0 References

(1) Solar Thermal Energy Conversion Program Summary, October 1976, ERDA 76-159

(2) Solar Position Paper No. 75-117, Prepared as Part of the Goldstone Energy System Study by Burns and Roe, for the Jet Propulsion Laboratory

(3) Technical Feasibility Study of Modular Dish Solar Electric Systems, March 1976, ERDA/NASA/ 19740-76/1

(4) Energy Storage and Power Conditioning Aspects of Photovoltaic Solar Power Systems, First Quarterly Report, October 1975, COO/2745-75/51 Performed under Contract No. E(11-1)-2748

SECTION XX

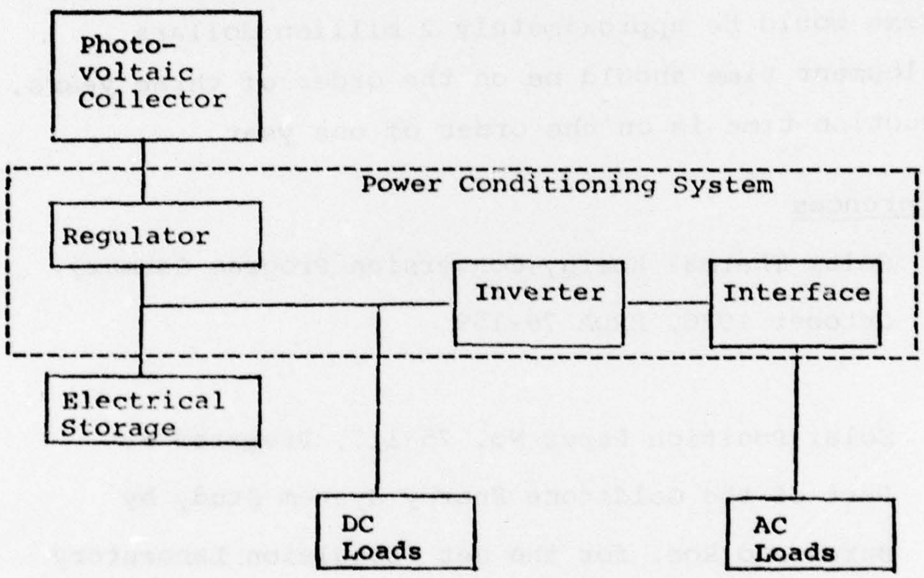
PHOTOVOLTAIC SYSTEM (SOLAR)

1.0 SYSTEM DESCRIPTION

1.1 System Identification

Fuel Converter: Photovoltaic Collector
Energy Converter Cycle: Direct Conversion
Fuel: Solar
Working Fluid: None

1.2 System Definition



A photovoltaic system consists of a silicon photovoltaic collector, a power conditioning system and an energy storage system. The energy storage system provides d-c voltage during periods of low or absent solar insolation. The power conditioning system consists of: a regulator to regulate the d-c voltage and current from the solar array; an inverter to convert d-c voltage to a-c; and an interface to connect the solar power system to the a-c loads.

1.3 Physical Description

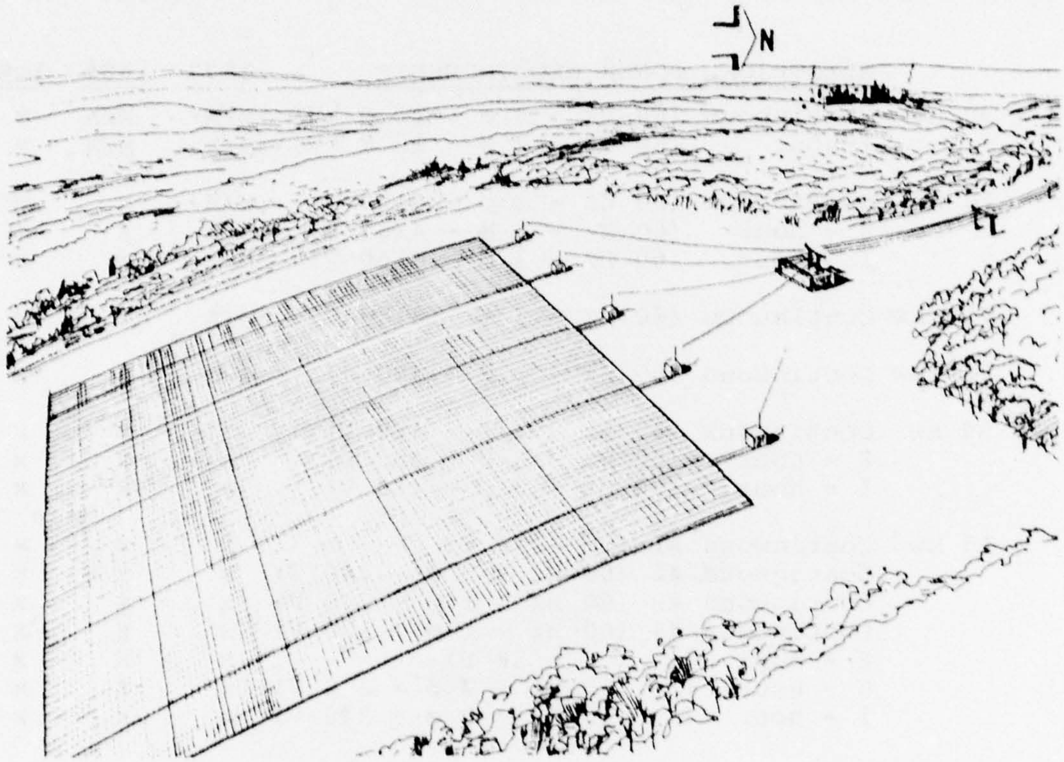


Figure 25. Conceptual design of a 25 MW photovoltaic power system covering one square mile

2.0 LIST OF REQUIREMENTS AND TIME FRAMES

This power system is applicable to the following electrical power requirements as marked. The first date listed indicates the earliest time when the system will be available for purchase. Later dates indicate the point in time when significant improvements are expected.

	ELECTRICAL POWER REQUIREMENTS		1977	1985	1995
50 Mw	Continuous	(60 Hz - 3 ø - 13.8 kV)	N/A*	N/A	x
	1-hour	(60 Hz - 3 ø - 13.8 kV)	N/A	N/A	x
10 Mw	Continuous	(60 Hz - 3 ø - 4160 V)	N/A	x	x
	8 - hour	(60 Hz - 3 ø - 4160 V)	N/A	x	x
	1 - hour	(60 Hz - 3 ø - 4160 V)	N/A	x	x
750 kw	Continuous	(60 Hz - 3 ø - 4160 V)	N/A	x	x
250 kw	Continuous	(60 Hz - 3 ø - 480 V)	N/A	x	x
50 kw	Continuous	(60 Hz - 3 ø - 480 V)	x	x	x
	8 - hour	(60 Hz - 3 ø - 480 V)	x	x	x
	1 - hour	(60 Hz - 3 ø - 480 V)	x	x	x
10 kw	Continuous #1	(DC - 28 V)	x	x	x
	Continuous #2	(60 Hz - 3 ø - 240 V)	x	x	x
	Continuous #3	(60 Hz - 1 ø - 240 V)	x	x	x
	Continuous #4	(60 Hz - 1 ø - 120 V)	x	x	x
	8 - hour #1	(DC - 28 V)	x	x	x
	8 - hour #2	(60 Hz - 3 ø - 240 V)	x	x	x
	1 - hour	(60 Hz - 3 ø - 240 V)	x	x	x

* The largest requirements cannot be met until the later date due to lack of production capacity, interfacing, and developed technology

3.0 PARAMETERS

3.1 Acquisition Cost (1977 Dollars)

Requirement	1977	1985	1995
50 Mw Cont.	3657×10^6	538×10^6	148×10^6
1 hr.	688×10^6	103×10^6	28.9×10^6
10 Mw Cont.	732×10^6	108×10^6	29.7×10^6
8 hr.	270×10^6	38.9×10^6	10.4×10^6
1 hr.	138×10^6	21×10^6	5.94×10^6
750 kw Cont.	54.9×10^6	8.14×10^6	2.25×10^6
250 kw Cont.	18.33×10^6	2.73×10^6	$.76 \times 10^6$
50 kw Cont.	3.67×10^6	$.55 \times 10^6$	$.15 \times 10^6$
8 hr.	1.37×10^6	$.20 \times 10^6$	58,000
1 hr.	$.7 \times 10^6$	115,000	36,000
10 kw Cont. #1	734,000	112,000	32,000
Cont. #2	734,000	112,000	32,000
Cont. #3	734,000	112,000	32,000
Cont. #4	734,000	112,000	32,000
8 hr. #1	277,000	44,000	13,000
8 hr. #2	277,000	44,000	13,000
1 hr.	142,000	26,000	8,000

A. Acquistion Cost Breakdown

1. Silicon Collectors - Present Day Cost (1977 Dollars x 10^6)

a. Continuous Operation

Plant Size	Photovaltaic Collectors	Battery Storage and Inverters	20 Percent Contingency	Total Capital Cost
10 KWe	.6	.014	.122	.734
50 KWe	3.0	.05	.612	3.67
250 KWe	15.0	.275	3.055	18.33
750 KWe	45.0	.787	9.15	54.9
10 MWe	600.0	10.0	122	732
50 MWe	3000.0	48.0	609	3657

b. 8 Hours or Less Operation

Plant Size	Photovaltaic Collectors	Battery Storage and Inverters	20 Percent Contingency	Total Capital Cost
10 KWe	.225	.0065	.04	.277
50 KWe	1.125	.022	.23	1.377
10 MWe	225	2.5	45	270

c. 1 Hour or Less/Day

Plant Size	Photovaltaic Collectors	Battery Storage and Inverters	20 Percent Contingency	Total Capital Cost
10 KWe	.112	.0065	.023	.142
50 KWe	.562	.022	.11	.702
10 KWe	112.5	2.5	23	138
50 MWe	562.5	11.25	114.7	688.44

Acquistion costs are based on a site in Southern California.

2. Silicon Collectors - Future Costs (Goals) (1977 Dollars x 10^6)

a. Continuous Operation

Plant Size	1985	1995-2000
10 KWe	.112	.032
50 KWe	.550	.155
250 KWe	2.73	.758
750 KWe	8.14	2.25
10 MWe	108.0	29.7
50 MWe	538.0	148

b. 8 Hours or Less Operation

Plant Size	1985	1995-2000
10 KWe	.044	.013
50 KWe	.207	.058
10 MWe	38.9	10.4

c. 1 Hour or Less/Day

Plant Size	1985	1995-2000
10 KWe	.026	.008
50 KWe	.115	.036
10 MWe	21.0	5.94
50 MWe	103	28.9

Acquisition costs are based on a site in Southern California.

3.2 Life Cycle Cost (1977 Dollars)

The life cycle cost (LCC) formula applicable to this system is:

LCC = AC + OMC

where AC = Acquisition Cost (see Section 3.1)

OMC = Operation and Maintenance Cost Over System Lifetime (see Section 3.15)

Requirement	1977		1985		1995	
	LCC	LCC/YR	LCC	LCC/YR	LCC	LCC/YR
50 Mw Cont.	$4{,}500 \times 10^6$	450×10^6	807×10^6	80,700,000	296,000,000	14,800,000
1 hr.	843×10^6	84.3×10^6	154×10^6	15,450,000	57,800,000	2,890,000
10 Mw Cont.	900×10^6	90×10^6	162×10^6	16,200,000	59,400,000	2,970,000
8 hr.	405×10^6	40.5×10^6	58,400,000	5,840,000	20,800,000	1,040,000
1 hr.	207×10^6	20.7×10^6	31,500,000	3,150,000	11,880,000	594,000
750 kw Cont.	67.5×10^6	6.75×10^6	12,210,000	1,221,000	4,500,000	225,000
250 kw Cont.	22.5×10^6	2.2×10^6	4,090,000	409,000	1,520,000	75,800
50 kw Cont.	5.5×10^6	$.55 \times 10^6$	825,000	82,500	310,000	15,500
8 hr.	2.0×10^6	$.2 \times 10^6$	310,000	31,000	116,000	5,800
1 hr.	1.75×10^6	$.175 \times 10^6$	172,000	17,200	72,000	3,600
10 kw Cont. #1	1.1×10^6	$.110 \times 10^6$	168,000	16,800	64,000	3,200
Cont. #2	1.1×10^6	$.110 \times 10^6$	168,000	16,800	64,000	3,200
Cont. #3	1.1×10^6	$.110 \times 10^6$	168,000	16,800	64,000	3,200
Cont. #4	1.1×10^6	$.110 \times 10^6$	168,000	16,800	64,000	3,200
8 hr. #1	415,000	41,500	66,000	6,600	26,000	1,300
8 hr. #2	415,000	41,500	66,000	6,600	26,000	1,300
1 hr.	213,000	21,000	39,000	3,900	16,000	800

3.3 Lifetime (Years)

Requirement	1977	1985	1995
50 Mw Cont.	10	10	20
1 hr.	10	10	20
10 Mw Cont.	10	10	20
8 hr.	10	10	20
1 hr.	10	10	20
750 kw Cont.	10	10	20
250 kw Cont.	10	10	20
50 kw Cont.	10	10	20
8 hr.	10	10	20
1 hr.	10	10	20
10 kw Cont. #1	10	10	20
Cont. #2	10	10	20
Cont. #3	10	10	20
Cont. #4	10	10	20
8 hr. #1	10	10	20
8 hr. #2	10	10	20
1 hr.	10	10	20

Present lifetime for photovoltaic collectors is ten years. Goal is twenty year life for 1995-2000 period.

3.4 Volume/Size

	Approximate Land Area Required	
	1977, 85, 95	
Requirement	sq. ft.	sq. m.
50 Mw Cont.	25,000,000	709,000
1 hr.	4,700,000	133,000
10 Mw Cont.	5,000,000	142,000
8 hr.	1,875,000	53,000
1 hr.	937,500	26,000
750 kw Cont.	375,000	10,600
250 kw Cont.	125,000	3,500
50 kw Cont.	25,000	700
8 hr.	9,375	270
1 hr.	4,700	130
10 kw Cont. #1	5,000	140
Cont. #2	5,000	140
Cont. #3	5,000	140
Cont. #4	5,000	140
8 hr. #1	1,875	50
8 hr. #2	1,875	50
1 hr.	940	26

3.5 **Weight**

Requirement	1977	
	lb	kg
50 Mw Cont.	151,000,000	68,400,000
1 hr.	35,400,000	16,000,000
10 Mw Cont.	30,000,000	13,800,000
8 hr.	8,950,000	4,050,000
1 hr.	7,080,000	3,200,000
750 kw Cont.	2,265,000	1,026,000
250 kw Cont.	755,000	342,000
50 kw Cont.	151,000	68,000
8 hr.	44,800	20,300
1 hr.	35,400	16,000
10 kw Cont. #1	30,200	13,700
Cont. #2	30,200	13,700
Cont. #3	30,200	13,700
Cont. #4	30,200	13,700
8 hr. #1	8,950	4,050
8 hr. #2	8,950	4,050
1 hr.	7,080	3,200

System can be made modular. Weights for higher power requirements are multiples of the 10 kw module. Weights for equipment should decrease for the 1985 and 2000 time periods.

3.6 Fuel

Plant performance is determined by the rate and type of solar radiation that would be received by the photovoltaic collector. No fuel is used other than solar radiation.

To determine the actual plant output for each site a solar model must be developed. Approximate variations in plant output from the base southwestern site used for the system presented herein can be determined from the map of solar isolation for the United States included in Appendix A. For the continuous use plant with 18 hours storage, the load factor possible is greater than .70 for a southwestern site. To achieve a high availability for the 8 hours or less and the 1 hour or less plants, a 3 hour battery storage requirement has been assumed.

3.7 <u>Environmental Constraints</u>

The environmental constraints of the power system are indicated in the following tabulation:

X amount of uncontrolled emission

Y Amount of pollution which would be emitted with no controls

Z Degree of difficulty in meeting more strict regulations

Key: blank - none
0 - minor
◐ - moderate
● - major

Emissions	X	Y	Z
Thermal Discharge (a)	-	-	-
Thermal Discharge (b)	-	-	-
Air Pollution			
CO	-	-	-
HC	-	-	-
NO_x	-	-	-
SO_x	-	-	-
Particulates	-	-	-
Noise	-	-	-
Solid Waste	-	-	-
Chemical Waste	-	-	-
Radioactive Waste	-	-	-

Notes: (a) system is air or water cooled; heat rejected directly to atmosphere.
(b) system is water cooled; heat rejected to body of water or cooling tower. Water source and/or make-up required.

3.8 Location Constraints

The locational limitations of the power system, and the degree of difficulty in overcoming these limitations are indicated in the following tabulation.

— - no difficulty

O - minor difficulty

◐ - major difficulty

● - overriding limitation

LOCATION RESTRAINT	
Water required for cooling	-
Water required for process	-
Manning required during operation	-
Fuel deliveries required	-
Adequate solar insolation required	●
Adequate wind speed required	-
Isolation from population required	-
Electricity required for charging	-

3.9 Operational Constraints

The tabulated operating characteristics are applicable to the power system as indicated.

— - Characteristic not observed in system operation

O - Characteristic has minor effect on system performance

◐ - Characteristic has moderate effect on system performance

● - Characteristic has major effect on system performance

Operational Restraint	
Efficiency reduction at part load	-
Part load capability limitation	-
Dependence on solar insolation	●
Dependence on wind consistency	-
Overload capacity limitations	-
Delayed response to rapid load changes	-
Life reduction from frequent rapid load changes	-

3.10 System Efficiency

Requirement	1977	Future Goals
50 Mw Cont.	5 to 10%	10 to 15%
1 hr.	5 to 10	10 to 15
10 Mw Cont.	5 to 10	10 to 15
8 hr.	5 to 10	10 to 15
1 hr.	5 to 10	10 to 15
750 kw Cont.	5 to 10	10 to 15
250 kw Cont.	5 to 10	10 to 15
50 kw Cont.	5 to 10	10 to 15
8 hr.	5 to 10	10 to 15
1 hr.	5 to 10	10 to 15
10 kw Cont. #1	5 to 10	10 to 15
Cont. #2	5 to 10	10 to 15
Cont. #3	5 to 10	10 to 15
Cont. #4	5 to 10	10 to 15
8 hr. #1	5 to 10	10 to 15
8 hr. #2	5 to 10	10 to 15
1 hr.	5 to 10	10 to 15

3.11 Type of System

Requirement	1977, 85, 95			Construction Time (Years)
	Mobile	Transp.	Fixed	
50 Mw Cont.			X	1
1 hr.			X	1
10 Mw Cont.			X	1
8 hr.			X	1
1 hr.			X	1
750 kw Cont.			X	½
250 kw Cont.			X	½
50 kw Cont.			X	½
8 hr.				
1 hr.				
10 kw Cont. #1			X	¼
Cont. #2			X	¼
Cont. #3			X	¼
Cont. #4			X	¼
8 hr. #1			X	¼
8 hr. #2			X	¼
1 hr.			X	¼

The system is transportable in pieces for installation at a fixed site. Separate photovoltaic arrays, battery bank, inverter controls, and interconnecting wiring must be assembled at the site.

3.12 Start-up, Shut-down Times

Requirement	1977, 85, 90 Start-up	Shut-down
50 Mw Cont.	½ sec.*	½ sec.
1 hr.	½ sec.	½ sec.
10 Mw Cont.	½ sec.	½ sec.
8 hr.	½ sec.	½ sec.
1 hr.	½ sec.	½ sec.
750 kw Cont.	½ sec.	½ sec.
250 kw Cont.		
50 kw Cont.	½ sec.	½ sec.
8 hr.	½ sec.	½ sec.
1 hr.	½ sec.	½ sec.
10 kw Cont. #1	½ sec.	½ sec.
Cont. #2	½ sec.	½ sec.
Cont. #3	½ sec.	½ sec.
Cont. #4	½ sec.	½ sec.
8 hr. #1	½ sec.	½ sec.
8 hr. #2	½ sec.	½ sec.
1 hr.	½ sec.	½ sec.

Times shown assume start-up and shut-down on battery storage. The photovoltaic collectors should not be connected to the load for approximately 15 minutes after the beginning of illumination. This will allow a stable operating condition to be established.

3.13 Growth Potential

This type of system is modular in nature such the growth is easily obtained by adding additional modules at a site.

3.14 Reliability

The tabulated conditions exist in the power system to the extent indicated.

— - Condition does not exist in system

O - Condition exists, but its extent is sufficiently minor as to have minimal effect on system performance or reliability

◐ - Condition exists, and its extent is sufficient to have a moderate effect on system performance or reliability

● - Condition exists and is a governing factor in determining system performance and reliability.

Conditions	
Numerous moving parts	-
High temperature operation	0
High stress levels	-
High radiation level	-
Corrosive attack	0
Thermal cycling	-
Non-modular design	-
Solar insolation required	●
Wind required	-

3.15 Maintenance and Operation

Requirement	Cost Per Year 1977	Cost Per Year 1985	Cost Per Year 1995	Overhaul Duration All	Personnel Required Cont. All
50 Mw Cont.	150,000,000	26,900,000	14,800,000	Not known	Yes
1 hr.	28,000,000	5,150,000	2,890,000	Not known	
10 Mw Cont.	30,000 000	5,400,000	2,900,000	Not known	Yes
8 hr.	13,500,000	1,950,000	1,040,000	Not known	
1 hr.	6,900,000	1,050,000	594,000	Not known	
750 kw Cont.	2,250,000	400,000	225,000	Not known	No
250 kw Cont.	750,000	136,000	75,800	Not known	No
50 kw Cont.	193,000	27,500	15,500	Not known	No
8 hr.	69,000	10,300	5,800	Not known	
1 hr.	35,000	5,700	3,600	Not known	
10 kw Cont. #1	36,700	5,600	3,200	Not known	No
Cont. #2	36,700	5,600	3,200	Not known	
Cont. #3	36,700	5,600	3,200	Not known	
Cont. #4	36,700	5,600	3,200	Not known	
8 hr. #1	13,800	2,200	1,300	Not known	
8 hr. #2	13,800	2,200	1,300	Not known	
1 hr.	7,100	1,300	800	Not known	

Maintenance costs are higher than for conventional power systems due to the large number of photovoltaic arrays. These arrays must be cleaned and serviced on a periodic basis.

3.16 Other Energy Production

Non concentrating collectors are assumed for this study. Since these collectors operate at relatively low temperatures, no cooling system is employed, and therefore no waste heat is available. Concentrating collectors could produce heat as well as electricity when they are sufficiently developed.

3.17 Availability of Raw Building Materials

Availability of battery materials such as lead may be a problem for the short term batteries.

3.18 Development

Development Program Cost and Duration :

Technology is developed but very costly. ERDA Division of Solar Energy is sponsoring a billion dollar research program to reduce the cost of photovoltaic devices. Goal is to produce low cost devices for power production in the 1990's.

4.0 References

(1) Energy Futures-Industries and the New Technologies by Stewart W. Herman and James S. Cannon, published 1976 by Inform, Inc.

(2) Photoboltaic Conversion Program, ERDA 76-161, November 1976.

(3) Energy Storage and Power Conditioning Aspects of Solar Power Systems, C00/2748-75/71, Bechtel Corporation, for ERDA.

(4) Conference, Burns and Roe, WPAFB on Photovoltaics held May 26, 1977.

SECTION XXI

WIND TURBINE GENERATOR (WIND)

1.0 SYSTEM DESCRIPTION

1.1 System Identification

Energy converter/Cycle - wind turbine generator

Fuel - none (extracts energy from the wind)

Working Fluid - atmospheric air

Equivalent Alternate Types - none

1.2 System Definition

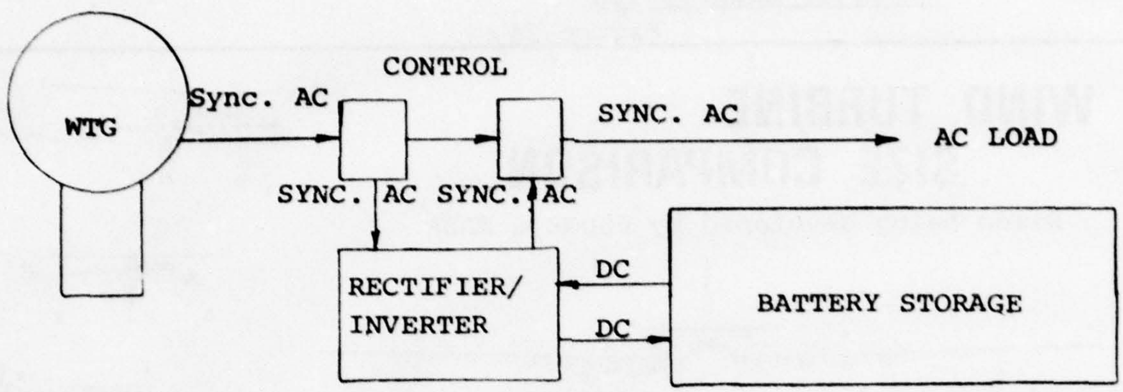
The major components of the power system consist of the wind turbine-generator combination, supporting structure (tower), control unit, battery storage, and a DC to AC inverter for AC electrical loads.

The energy contained in the wind is proportional to its velocity cubed. As a result, the economics of wind-electric generation is strongly site dependent, since fewer turbines are needed to generate the same amount of electricity at a high wind speed site, as opposed to a low wind speed site. To account for this variability, two yearly average wind speeds have been chosen for this analysis; one representing the poorest conditions which might normally be considered for wind generation (10 mph average windspeed) and one representing very favorable conditions (20 mph average wind speed). This produces an effective upper and lower bound on cost,

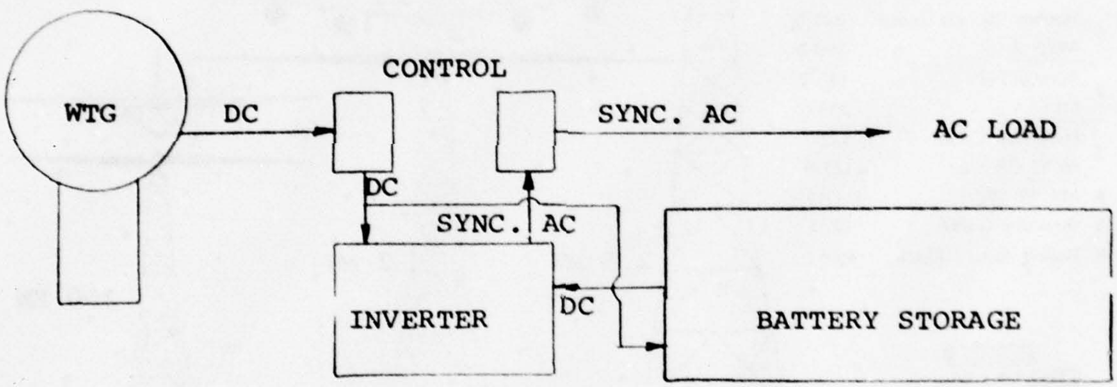
and will enable the user to determine if wind-electric generation is a candidate system for his site. If it is, a detailed analysis of site wind conditions will be needed to determine the exact economics.

Another variable which effects cost, but to a lesser degree, is the amount of storage capacity included in the wind turbine-generator system. In a given month, a wind turbine-generator will produce the number of kilowatt-hours of electricity commensurate with the average wind speed of the site. On an instantaneous basis, however, the kilowatts of electricity being generated will vary with the wind speed, which is constantly fluctuating. To smooth out these fluctuations, energy storage is used so that excess electricity generated during the windiest periods can be used to supplement low generation during calm periods. The larger the storage capacity employed, the smaller the chance of electric power interruption and the higher the capital cost. Two different storage capacities were used for this analysis; one day storage which minimizes capital cost, and five day storage which would substantially decrease the risk of power interruption, but at increased cost.

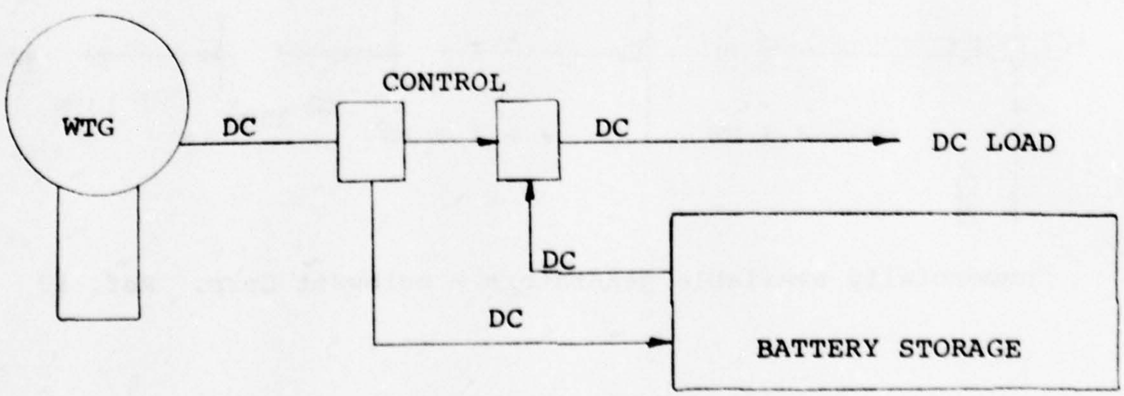
CONFIGURATION #1 LARGE REQUIREMENTS



CONFIGURATION #2 SMALL REQUIREMENTS - AC LOADS

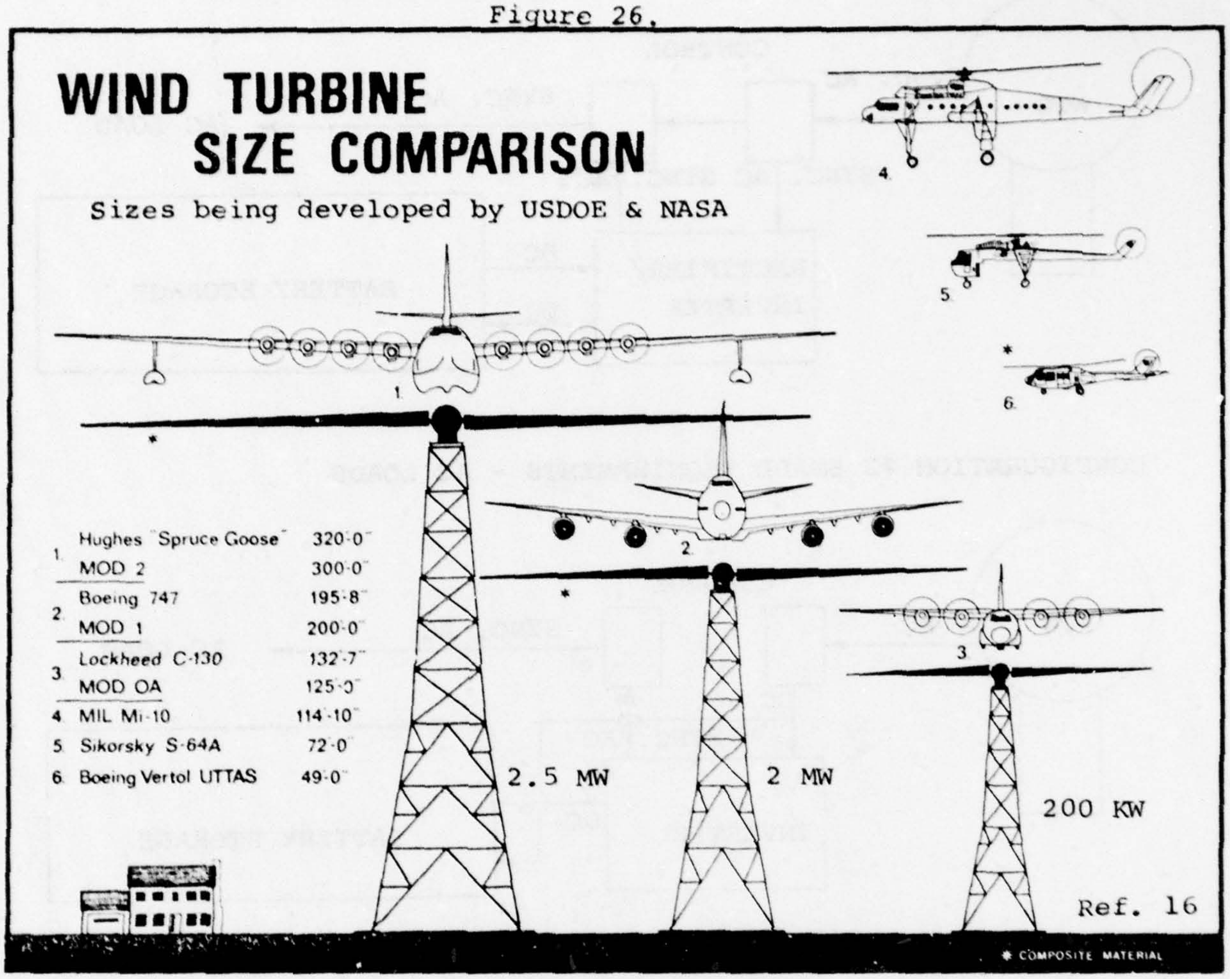


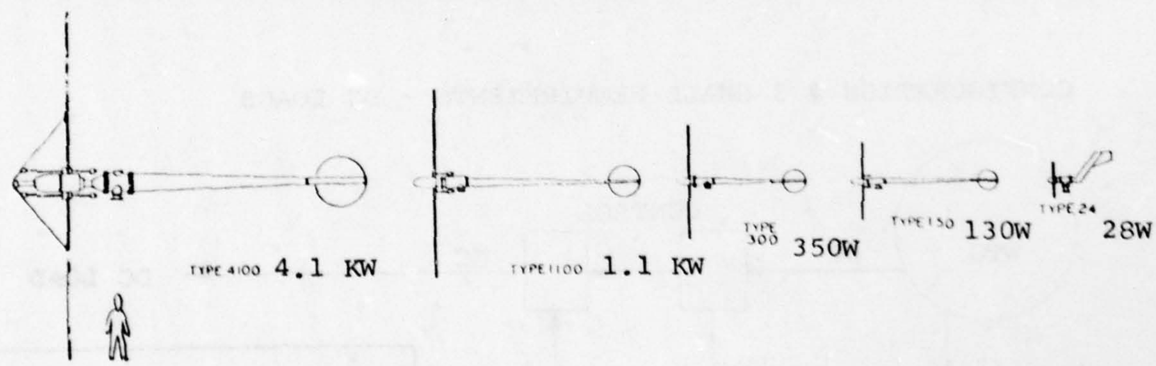
CONFIGURATION # 3 SMALL REQUIREMENTS - DC LOADS



1.3 Physical Description

Figure 26.





Commercially available generators - Aerowatt Corp. Ref. 13

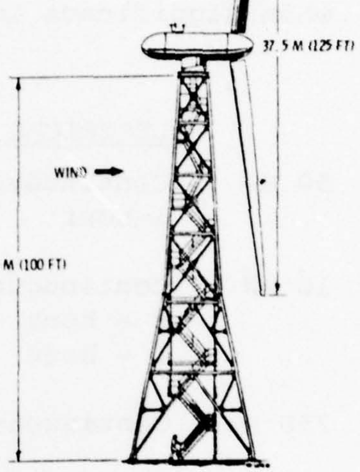


Figure 27.
ERDA-NASA EXPERIMENTAL WIND TURBINE GENERATOR – 100 kW TEST BED

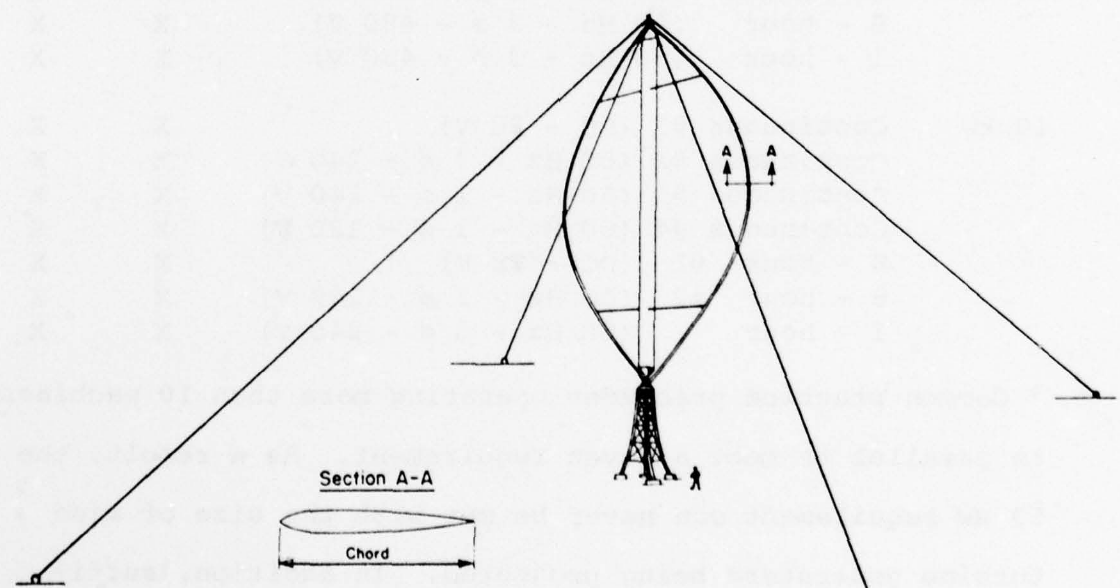


Figure 28.
Experimental 200 KW vertical axis wind turbine-generator, designed by the National Research Council of Canada, will be installed at a site in the Magdalen Islands.

2.0 LIST OF REQUIREMENTS AND TIME FRAMES

This power system is applicable to the following electrical power requirements as marked. The first date listed indicates the earliest time when the system will be available for purchase. Later dates indicate the point in time when significant improvements are expected.

	ELECTRICAL POWER REQUIREMENTS	1977	1985
50 Mw	Continuous (60 Hz - 3 ø - 13.8 kV)	N/A*	N/A
	1-hour (60 Hz - 3 ø - 13.8 kV)	N/A	N/A
10 MW	Continuous (60 Hz - 3 ø - 4160 V)	N/A	X
	8 - hour (60 Hz - 3 ø - 4160 V)	N/A	X
	1 - hour (60 Hz - 3 ø - 4160 V)	N/A	X
750 kw	Continuous (60 Hz - 3 ø - 4160 V)	N/A	X
250 kw	Continuous (60 Hz - 3 ø - 480 V)	N/A	X
50 kw	Continuous (60 Hz - 3 ø - 480 V)	X	X
	8 - hour (60 Hz - 3 ø - 480 V)	X	X
	1 - hour (60 Hz - 3 ø - 480 V)	X	X
10 kw	Continuous #1 (DC - 28 V)	X	X
	Continuous #2 (60 Hz - 3 ø - 240 V)	X	X
	Continuous #3 (60 Hz - 1 ø - 240 V)	X	X
	Continuous #4 (60 Hz - 1 ø - 120 V)	X	X
	8 - hour #1 (DC - 28 V)	X	X
	8 - hour #2 (60 Hz - 3 ø - 240 V)	X	X
	1 - hour (60 Hz - 3 ø - 240 V)	X	X

* Common practice precludes operating more than 10 machines in parallel to meet a given requirement. As a result, the 50 Mw requirement can never be met with the size of wind turbine generaters being projected. In addition, sufficiently large units are not currently available to meet requirements larger than 50 kw.

3.0 PARAMETERS

3.1 Acquisition Cost (1977 Dollars)

10 Miles Per Hour Average Wind Speed

Requirement	1977 1 Day Storage	1977 5 Day Storage	1985 1 Day Storage	1985 5 Day Storage
10 Mw Cont.	-	-	23,955,000	58,106,000
10 Mw 8 Hr.	-	-	14,069,000	30,331,000
10 Mw 1 Hr.	-	-	2,779,000	4,812,000
750 kw Cont.	-	-	1,845,000	4,407,000
250 kw Cont.	-	-	781,000	1,635,000
50 kw Cont.	601,000	1,012,000	147,300	331,000
50 kw 8 Hr.	367,000	563,000	65,600	153,600
50 kw 1 Hr.	58,300	71,600	53,200	60,200
10 kw Cont. DC	106,000	148,000	100,600	123,000
10 kw Cont. AC	121,000	166,000	114,700	138,000
10 kw 8 Hr. DC	54,800	75,100	52,400	63,000
10 kw 8 Hr. AC	73,600	95,000	70,400	81,600
10 kw 1 Hr.	11,700	14,400	10,700	12,100

20 Miles Per Hour Average Wind Speed

Requirement	1977 1 Day Storage	1977 5 Day Storage	1985 1 Day Storage	1985 5 Day Storage
10 Mw Cont.	-	-	15,312,000	49,463,000
10 Mw 8 Hr.	-	-	8,628,000	24,890,000
10 Mw 1 Hr.	-	-	2,114,000	4,147,000
750 kw Cont.	-	-	1,372,000	3,934,000
250 kw Cont.	-	-	457,000	1,311,000
50 kw Cont.	192,000	603,000	72,900	257,000
50 kw 8 Hr.	114,000	309,000	36,900	125,000
50 kw 1 Hr.	22,200	35,500	17,100	24,100
10 kw Cont. DC	33,400	76,100	28,300	50,700
10 kw Cont. AC	38,400	83,200	32,400	55,800
10 kw 8 Hr. DC	17,000	37,300	14,600	25,200
10 kw 8 Hr. AC	22,700	44,100	19,500	30,700
10 kw 1 Hr.	5,200	7,900	4,200	5,600

3.2 Life Cycle Cost (1977 Dollars)

The life cycle cost is defined by the following equation:

LCC = AC + OMC

where AC = Acquisition Cost (see Section 3.1)

OMC = Operation and Maintenance Cost over System Lifetime (see Section 3.15)

10 Miles Per Hour Average Wind Speed

Requirement	LCC 1977 1 Day Storage	LCC/YR 1977 1 Day Storage	LCC 1977 5 Day Storage	LCC/YR 1977 5 Day Storage	LCC 1985 1 Day Storage	LCC/YR 1985 1 Day Storage	LCC 1985 5 Day Storage	LCC/YR 1985 5 Day Storage
10 Mw Cont.	–	–	–	–	28,247,000	1,412,000	62,398,000	3,120,000
10 Mw 8 Hr.	–	–	–	–	16,113,000	806,000	32,375,000	1,619,000
10 Mw 1 Hr.	–	–	–	–	3,035,000	152,000	5,068,000	253,000
750 kw Cont.	–	–	–	–	5,064,000	253,000	7,626,000	381,000
250 kw Cont.	–	–	–	–	1,854,000	92,700	2,708,000	135,000
50 kw Cont.	685,600	34,300	1,508,000	75,400	176,000	8,800	360,000	18,000
50 kw 8 Hr.	407,700	20,400	798,300	39,900	79,400	4,000	167,000	8,400
50 kw 1 Hr.	63,400	3,200	90,000	4,500	54,900	2,700	61,900	3,100
10 kw Cont. DC	121,900	6,100	207,300	10,400	101,000	5,300	129,000	6,400
10 kw Cont. AC	137,700	6,900	227,300	11,400	121,000	6,000	144,000	7,200
10 kw 8 Hr. DC	62,500	3,100	103,100	5,200	55,000	2,800	65,600	3,300
10 kw 8 Hr. AC	81,700	4,100	124,500	6,200	73,200	3,700	84,400	4,200
10 kw 1 Hr.	13,000	700	18,400	900	11,300	570	12,700	640

20 Miles Per Hour Average Wind Speed

Requirement	LCC 1977 1 Day Storage	LCC/YR 1977 1 Day Storage	LCC 1977 5 Day Storage	LCC/YR 1977 5 Day Storage	LCC 1985 1 Day Storage	LCC/YR 1985 1 Day Storage	LCC 1985 5 Day Storage	LCC/YR 1985 5 Day Storage
10 Mw Cont.	–	–	–	–	19,604,000	980,000	53,755,000	2,688,000
10 Mw 8 Hr.	–	–	–	–	10,672,000	534,000	26,934,000	1,347,000
10 Mw 1 Hr.	–	–	–	–	2,370,000	118,000	4,403,000	220,000
750 kw Cont.	–	–	–	–	4,591,000	230,000	7,153,000	358,000
250 kw Cont.	–	–	–	–	1,530,000	76,500	2,384,000	119,000
50 kw Cont.	276,600	13,800	1,099,000	54,900	102,000	5,100	286,000	14,300
50 kw 8 Hr.	154,200	7,700	544,800	27,200	50,700	2,500	139,000	6,900
50 kw 1 Hr.	27,300	1,400	53,900	2,700	18,800	940	25,800	1,300
10 kw Cont. DC	49,600	2,500	135,000	6,800	33,800	1,700	56,200	2,800
10 kw Cont. AC	55,400	2,800	145,000	7,300	38,200	1,900	61,600	3,100
10 kw 8 Hr. DC	24,700	1,200	65,300	3,300	17,200	860	27,800	1,400
10 kw 8 Hr. AC	30,800	1,500	73,600	3,700	22,300	1,100	33,500	1,700
10 kw 1 Hr.	5,900	300	11,900	600	4,800	240	6,200	310

3.3 Lifetime (Years)

The useful lifetime of the power system is indicated in the following table:

Requirement	Lifetime (Years)
All	20*

* 1977 systems will require the replacement of the storage batteries (lead acid) after 10 years

3.4 Volume/Size

The land area occupied by the power system is indicated in the following tables. The wind turbine generator (WTG) area includes the minimum spacing required between multiple units to avoid interference effects in the air flow. The physical proportion of the units can be determined from Section 1.3.

10 Miles Per Hour 1977 1 Day Storage

Requirement	WTG Area Ft^2	Battery Area Ft^2	Total System Area Ft^2	Total System Area m^2
10 Mw Cont.	-	-	-	-
10 Mw 8 Hr.	-	-	-	-
10 Mw 1 Hr.	-	-	-	-
750 kw Cont.	-	-	-	-
250 kw Cont.	-	-	-	-
50 kw Cont.	11,800	441	12,200	1,140
50 kw 8 Hr.	7,360	210	7,570	700
50 kw 1 Hr.	1,110	27	1,140	110
10 kw Cont. DC	2,120	84	2,200	210
10 kw Cont. AC	2,450	88	2,540	240
10 kw 8 Hr. DC	1,140	40	1,180	110
10 kw 8 Hr. AC	1,470	42	1,510	140
10 kw 1 Hr.	340	5.5	350	32

10 Miles Per Hour 1977 5 Day Storage

Requirement	WTG Area Ft^2	Battery Area Ft^2	Total System Area Ft^2	Total System Area Ft^2
10 Mw Cont.	-	-	-	-
10 Mw 8 Hr.	-	-	-	-
10 Mw 1 Hr.	-	-	-	-
750 kw Cont.	-	-	-	-
250 kw Cont.	-	-	-	-
50 kw Cont.	11,800	2,200	14,000	1,300
50 kw 8 Hr.	7,360	1,050	8,400	780
50 kw 1 Hr.	1,110	130	1,240	120
10 kw Cont. DC	2,120	420	2,540	240
10 kw Cont. AC	2,450	440	2,890	270
10 kw 8 Hr. DC	1,140	200	1,340	120
10 kw 8 Hr. AC	1,470	210	1,680	160
10 kw 1 Hr.	340	27	370	34

10 Miles Per Hour 1985 1 Day Storage

Requirement	WTG Area Ft^2	Battery Area Ft^2	Total System Area Ft^2	Total System Area m^2
10 Mw Cont.	471,200	7,060	478,300	44,400
10 Mw 8 Hr.	282,700	3,360	286,100	26,600
10 Mw 1 Hr.	68,200	420	68,600	6,380
750 kw Cont.	43,700	530	44,200	4,110
250 kw Cont.	49,100	180	49,300	4,580
50 kw Cont.	12,300	35	12,300	1,150
50 kw 8 Hr.	12,300	17	12,300	1,140
50 kw 1 Hr.	1,110	2.1	1,110	100
10 kw Cont. DC	2,120	6.7	2,130	200
10 kw Cont. AC	2,450	7.0	2,460	230
10 kw 8 Hr. DC	1,140	3.2	1,140	110
10 kw 8 Hr. AC	1,470	3.4	1,470	140
10 kw 1 Hr.	340	0.4	340	32

10 Miles Per Hour 1985 5 Day Storage

Requirement	WTG Area Ft^2	Battery Area Ft^2	Total System Area Ft^2	Total System Area m^2
10 Mw Cont.	471,200	35,300	506,500	47,100
10 Mw 8 Hr.	282,700	16,800	299,500	27,800
10 Mw 1 Hr.	68,200	2,100	70,300	6,530
750 kw Cont.	43,700	2,650	46,400	4,310
250 kw Cont.	49,100	880	50,000	4,640
50 kw Cont.	12,300	180	12,500	1,160
50 kw 8 Hr.	12,300	84	12,400	1,150
50 kw 1 Hr.	1,110	11	1,120	100
10 kw Cont. DC	2,120	34	2,150	200
10 kw Cont. AC	2,450	35	2,490	230
10 kw 8 Hr. DC	1,140	16	1,160	110
10 kw 8 Hr. AC	1,470	17	1,490	140
10 kw 1 Hr.	340	2.1	340	32

20 Miles Per Hour 1977 1 Day Storage

Requirement	WTG Area Ft^2	Battery Area Ft^2	Total System Area Ft^2	Total System Area m^2
10 Mw Cont.	-	-	-	-
10 Mw 8 Hr.	-	-	-	-
10 Mw 1 Hr.	-	-	-	-
750 kw Cont.	-	-	-	-
250 kw Cont.	-	-	-	-
50 kw Cont.	2,950	441	3,390	320
50 kw 8 Hr.	1,830	210	2,040	190
50 kw 1 Hr.	350	27	380	35
10 kw Cont. DC	490	84	570	53
10 kw Cont. AC	620	88	710	66
10 kw 8 Hr. DC	350	40	390	36
10 kw 8 Hr. AC	500	42	540	50
10 kw 1 Hr.	130	5.5	140	13

20 Miles Per Hour 1977 5 Day Storage

Requirement	WTG Area Ft^2	Battery Area Ft^2	Total System Area Ft^2	Total System Area m^2
10 Mw Cont.	-	-	-	-
10 Mw 8 Hr.	-	-	-	-
10 Mw 1 Hr.	-	-	-	-
750 kw Cont.	-	-	-	-
250 kw Cont.	-	-	-	-
50 kw Cont.	2,950	2,200	5,150	480
50 kw 8 Hr.	1,830	1,050	2,880	270
50 kw 1 Hr.	350	130	480	45
10 kw Cont. DC	490	420	910	85
10 kw Cont. AC	620	440	1,060	98
10 kw 8 Hr. DC	350	200	550	51
10 kw 8 Hr. AC	500	210	710	66
10 kw 1 Hr.	130	27	160	15

20 Miles Per Hour 1985 1 Day Storage

Requirement	WTG Area Ft^2	Battery Area Ft^2	Total System Area Ft^2	Total System Area m^2
10 Mw Cont.	188,500	7,060	195,600	18,700
10 Mw 8 Hr.	127,500	3,360	130,700	12,200
10 Mw 1 Hr.	61,400	420	61,800	5,740
750 kw Cont.	61,400	530	61,900	5,750
250 kw Cont.	24,500	180	24,700	2,290
50 kw Cont.	12,300	35	12,300	1,150
50 kw 8 Hr.	12,300	17	12,300	1,140
50 kw 1 Hr.	350	2.1	350	33
10 kw Cont. DC	490	6.7	500	46
10 kw Cont. AC	620	7.0	630	58
10 kw 8 Hr. DC	350	3.2	350	33
10 kw 8 Hr. AC	500	3.4	500	47
10 kw 1 Hr.	130	0.4	130	12

20 Miles Per Hour 1985 5 Day Storage

Requirement	WTG Area Ft^2	Battery Area Ft^2	Total System Area Ft^2	Total System Area m^2
10 Mw Cont.	188,500	35,300	223,800	20,800
10 Mw 8 Hr.	127,500	16,800	144,300	13,400
10 Mw 1 Hr.	61,400	2,100	63,500	5,900
750 kw Cont.	61,400	2,650	64,100	5,950
250 kw Cont.	24,500	880	25,400	2,360
50 kw Cont.	12,300	180	12,500	1,160
50 kw 8 Hr.	12,300	84	12,400	1,150
50 kw 1 Hr.	350	11	360	34
10 kw Cont. DC	490	34	520	49
10 kw Cont. AC	620	35	660	61
10 kw Cont. DC	350	16	370	34
10 kw 8 Hr. AC	500	17	520	48
10 kw 1 Hr.	130	2.1	132	12

3.5 Weight

Weight is not a relevant parameter for fixed systems.

3.6 Fuel

The power system extracts power from the wind and therefore uses no fuel.

3.7 Environmental Constraints

The environmental constraints of the power system are indicated in the following tabulation:

X amount of uncontrolled emission

Y Amount of pollution which would be emitted with no controls

Z Degree of difficulty in meeting more strict regulations

Key: blank - none

0 - minor

● - moderate

● - major

Emissions	X	Y	Z
Thermal Discharge (a)	0	-	-
Thermal Discharge (b)	-	-	-
Air Pollution			
CO	-	-	-
HC	-	-	-
NO_x	-	-	-
SO_x	-	-	-
Particulates	-	-	-
Noise	0	-	-
Solid Waste	-	-	-
Chemical Waste	-	-	-
Radioactive Waste	-	-	-

Notes: (a) system is air or water cooled; heat rejected directly to atmosphere.
(b) system is water cooled; heat rejected to body of water or cooling tower. Water source and/or make-up required.

3.8 <u>Location Constraints</u>

The locational limitations of the power system, and the degree of difficulty in overcoming these limitations are indicated in the following tabulation.

— - no difficulty

O - minor difficulty

◐ - major difficulty

● - overriding limitation

LOCATION RESTRAINT	
Water required for cooling	-
Water required for process	-
Manning required during operation	-
Fuel deliveries required	-
Adequate solar insolation required	-
Adequate wind speed required	●
Isolation from population required	-
Electricity required for charging	-

3.9 Operational Restraints

The tabulated operating characteristics are applicable to the power system as indicated.

— - Characteristic not observed in system operation

O - Characteristic has minor effect on system performance

◐ - Characteristic has moderate effect on system performance

● - Characteristic has major effect on system performance

Operational Restraint	
Efficiency reduction at part load	-
Part load capability limitation	-
Dependence on solar insolation	-
Dependence on wind consistency	●
Overload capacity limitations*	●
Delayed response to rapid load changes	-
Life reduction from frequent rapid load changes	-

* Overload Capacity

— 115% or greater

O 110% - 115%

◐ 105% - 110%

● 105% or less

3.10 System Efficiency

The power system efficiency is indicated in the following tabulation:

Requirement	1977-85
10 Mw Cont.	20-28%*
10 Mw 8 hr.	20-28
10 Mw 1 hr.	20-28
750 kw Cont.	20-28
250 kw Cont.	20-28
50 kw Cont.	21-27
50 kw 8 hr.	21-27
50 kw 1 hr.	21-27
10 kw Cont. DC	22-28
10 kw Cont. AC	21-27
10 kw 8 hr. DC	22-28
10 kw 8 hr. AC	21-27
10 kw 1 hr.	21-27

*Efficiency is reduced when storage batteries and/or inverters are employed.

3.11 Type of System

The system type is indicated in the following tabulation.

M = mobile

T = transportable

F = fixed

Time = time for assembly or construction

Requirement	M	T	F	Time
10 MW Cont., 8 Hr.			x	1 yr
10 MW 1 Hr.			x	6 mo
750 kw Cont.			x	6 mo
250 kw Cont.			x	6 mo
50 kw Cont., 8 Hr.			x	6 mo
50 kw 1 Hr.			x	3 mo
10 kw All			x	3 mo

3.12 Start-up/Shut-down Times

The start-up and shut-down time for the power system is indicated in the following tabulation:

Requirement	Start-up	Shut-down
All	1/2 sec*	1/2 sec

*Response time fo the battery storage.

3.13 <u>Growth Potential</u>

The power system is not inherently modular in construction. However, since most requirements are met with multiple units, the degree of modularity is high and, therefore, the growth potential is good. Incremental increases in system capacity can be readily achieved.

3.14 Reliability

The tabulated conditions exist in the power system to the extent indicated.

— - Condition does not exist in system

O - Condition exists, but its extent is sufficiently minor as to have minimal effect on system performance or reliability

◐ - Condition exists, and its extent is sufficient to have a moderate effect on system performance or reliability

● - Condition exists and is a governing factor in determining system performance and reliability.

Conditions	
Numerous moving parts	O
High temperature operation	O
High stress levels	●
High radiation level	-
Corrosive attack	O
Thermal cycling	-
Non-modular design	-
Solar insolation required	-
Wind required	●

3.15 Maintenance and Operation

The annual maintenance and operating costs for the power system are listed in the following tabulation.

Requirement	Operation and Maintenance 1977 $/yr	Personnel Req'd. Continuously
10 MW Cont.	214,600	No
10 MW 8 Hr.	102,200	No
10 MW 1 Hr.	12,780	No
750 kw Cont.	161,000	No
250 kw Cont.	53,660	No
50 kw Cont.	1,450	No
50 kw 8 Hr.	690	No
50 kw 1 Hr.	87	No
10 kw Cont. DC	275	No
10 kw Cont. AC	290	No
10 kw 8 Hr. DC	130	No
10 kw 8 Hr. AC	140	No
10 kw 1 Hr.	30	No

3.16 <u>Other Energy Production</u>

No high grade heat is available from the power system.

3.17 <u>Availability of Raw Building Materials</u>

No scarce materials are required for the wind turbine generators themselves, lead, however, could be somewhat critical for the near term lead-acid storage batteries.

3.18 Development

The following WTG development projects are being funded or planned by the ERDA:

MOD-O

A 100 kw nominal wind turbine generator was designed and constructed by the NASA, and has been in operation at the Plum Brook Station, Ohio, since late 1976. This unit will serve as a test bed for WTG components.

MOD-OA

Three scaled up versions of the MOD-O, rated at 200 kw nominal, are being assembled by Westinghouse for erection and testing at three utility sites at the end of 1977.

MOD-1

General Electric has designed, and will erect two 2 MW nominal WTG units at site to be selected.

MOD-2

Boeing will design and erect a 2.5 MW nominal WTG under a $10-million ERDA contract. Completion is scheduled for 1979.

The above machines are of the horizontal axis or propeller type. There is also interest in the vertical

axis, Darrius type machine because of its potentially lower acquisition cost. Development work for this type is underway at Sandia Laboratories and also at The National Research Council of Canada.

The 1977 ERDA wind budget is $24-million. For 1978, this will be increased to $31.7 million. The development of the advanced WTG systems assumed in this analysis for 1985 purchase has relatively low risk, as compared to other types of advanced systems; since no technological breakthroughs are needed for their development.

4.0 REFERENCES

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SECTION XXII

FLYWHEEL STORAGE (EXTERNAL)

1.0 SYSTEM DESCRIPTION

1.1 System Identification

Energy Converter/Cycle - kinetic energy storage system utilizing rotating mass to drive electrical generator.

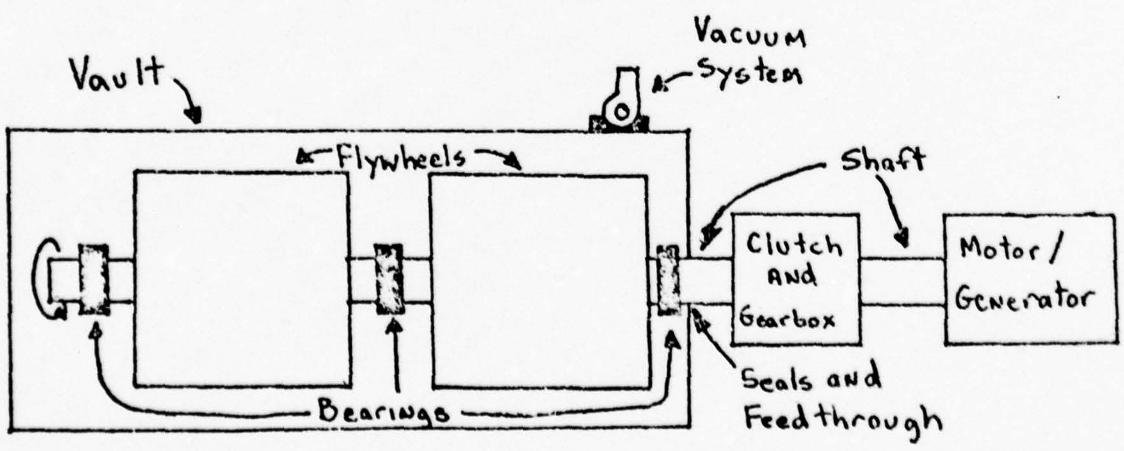
Fuel - None (system requires electricity for charging)

Working Fluid - none

Equivalent Alternate Types - none

1.2 System Definition

The system design examined in this section incorporates ganged flywheels on a common horizontal shaft feeding a variable frequency field machine and a common cycloconverter. Subsystems required include bearings, vacuum systems, support substructures, control systems, and foundation vaults. The design is a complete conceptual system for flywheel energy storage and represents a promising approach selected from many possible designs.



1.3 Physical Description

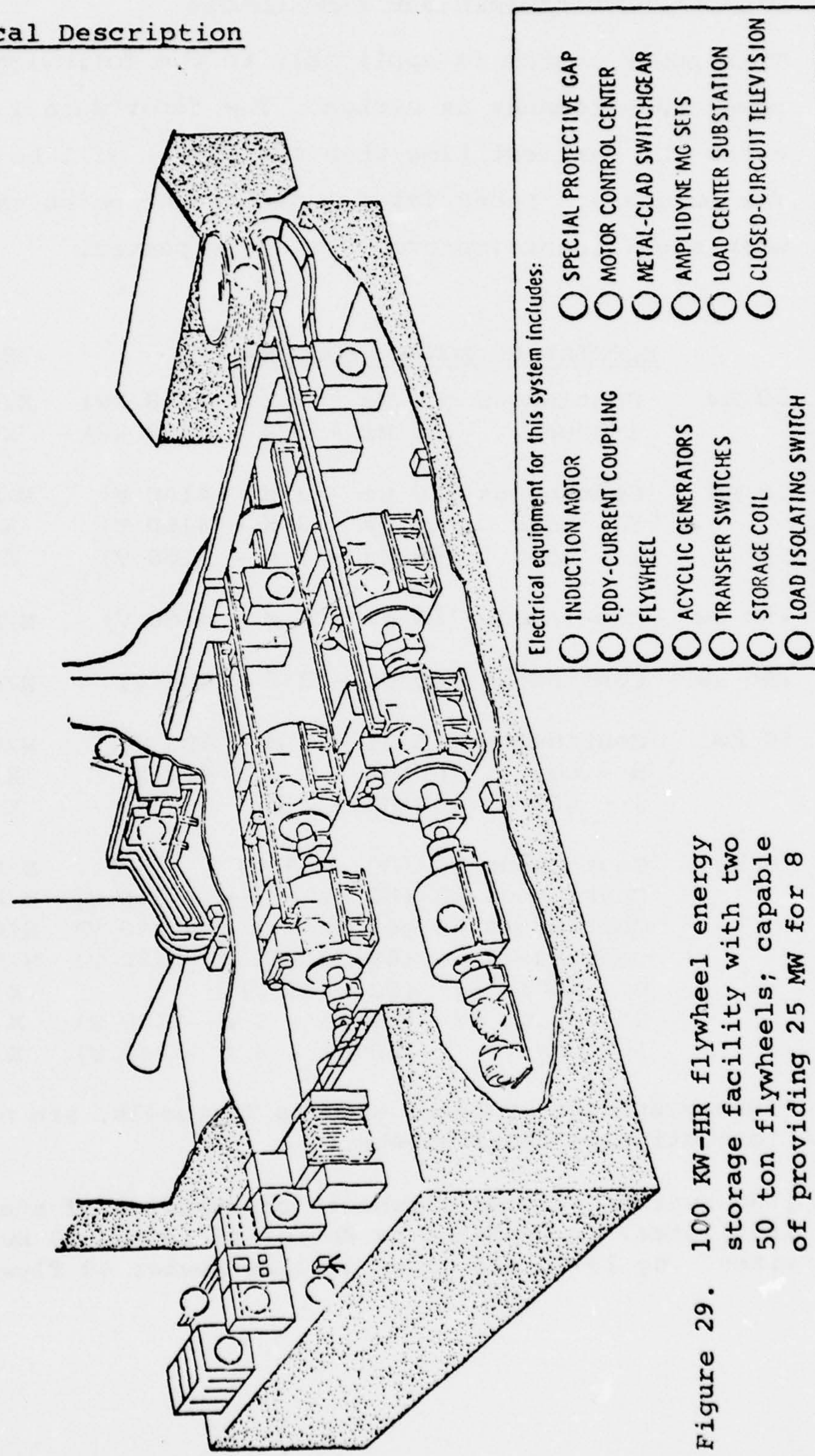


Figure 29. 100 KW-HR flywheel energy storage facility with two 50 ton flywheels; capable of providing 25 MW for 8 seconds

2.0 LIST OF REQUIREMENTS AND TIME FRAMES

This power system is applicable to the following electrical power requirements as marked. The first date listed indicates the earliest time when the system will be available for purchase. Later dates indicate the point in time when significant improvements are expected.

	ELECTRICAL POWER REQUIREMENTS		1980	1985	1990
50 Mw	Continuous	(60 Hz - 3 ø - 13.8 kV)	N/A*	N/A	N/A
	1-hour	(60 Hz - 3 ø - 13.8 kV)	X	X	X
10 MW	Continuous	(60 Hz - 3 ø - 4160 V)	N/A	N/A	N/A
	8 - hour	(60 Hz - 3 ø - 4160 V)	X	X	X
	1 - hour	(60 Hz - 3 ø - 4160 V)	X	X	X
750 kw	Continuous	(60 Hz - 3 ø - 4160 V)	N/A	N/A	N/A
250 kw	Continuous	(60 Hz - 3 ø - 480 V)	N/A	N/A	N/A
50 kw	Continuous	(60 Hz - 3 ø - 480 V)	N/A	N/A	N/A
	8 - hour	(60 Hz - 3 ø - 480 V)	X	X	X
	1 - hour	(60 Hz - 3 ø - 480 V)	X	X	X
10 kw	Continuous #1	(DC - 28 V)	N/A	N/A	N/A
	Continuous #2	(60 Hz - 3 ø - 240 V)	N/A	N/A	N/A
	Continuous #3	(60 Hz - 1 ø - 240 V)	N/A	N/A	N/A
	Continuous #4	(60 Hz - 1 ø - 120 V)	N/A	N/A	N/A
	8 - hour #1	(DC - 28 V)	X	X	X
	8 - hour #2	(60 Hz - 3 ø - 240 V)	X	X	X
	1 - hour	(60 Hz - 3 ø - 240 V)	X	X	X

*Energy storage systems, such as flywheels, are not applicable to continuous requirements.

1980 systems utilize flywheels constructed of steel. By 1985, steel is replaced by Kevlar 49 in the 10 kw and 50 kw sizes. By 1990, all sizes utilize Kevlar 49 flywheels.

3.1 <u>Acquisition Cost (1977 Dollars)</u>

Requirement	1980	1985	1990
50 MW 1 hr.	11,569,000	10,772,000	9,983,000
10 MW 8 hr.	12,582,000	11,517,000	10,467,000
10 MW 1 hr.	2,314,000	2,154,000	1,997,000
50 kw 8 hr.	707,000	163,000	125,000
50 kw 1 hr.	88,400	20,400	15,600
10 kw 8 hr. #1, 2	141,400	32,600	25,000
10 kw 1 hr.	17,700	4,100	3,100

3.2 <u>Life Cycle Cost</u>

Formula applicable to this system:

LCC = AC + OMC + EC

AC = Acquisition Cost (See Section 3.1)

OMC = Operation and Maintenance Cost Over System Lifetime (See Section 3.15)

EC = Electrical Cost (See Section 3.6)

Life cycle cost includes the cost of electricity to charge the system before its initial use and each subsequent use.

Requirement	LCC 10^3 1977 Dollars			LCC/YR 10^3 1977 Dollars		
	1980	1985	1990	1980	1985	1990
50 MW 1 hr.	35,394	34,597	33,808	1,416	1,384	1,352
10 MW 8 hr.	52,794	51,729	50,679	2,122	2,069	2,027
10 MW 1 hr.	7,077	6,918	6,761	283	277	270
50 KW 8 hr.	915.1	325.1	333.1	36.6	16.3	13.3
50 KW 1 hr.	114.2	40.4	41.4	4.57	2.02	1.65
10 KW 8 hr #1,2	182.5	64.6	66.1	7.30	3.23	2.64
10 KW 1 hr.	22.4	7.81	7.89	.90	.39	.32

3.3 Lifetime (years)

Requirement	1980	1985	1990
50 MW 1 hr.	25	25	25
10 MW 8 hr.	25	25	25
10 MW 1 hr.	25	25	25
50 kw 8 hr.	25	20	25
50 kw 1 hr.	25	20	25
10 kw 8 hr. #1,2	25	20	25
10 kw 1 hr.	25	20	25

3.4 Volume/Size

Requirement	Land Area					
	1980		1985		1990	
	ft^2	m^2	ft^2	m^2	ft^2	m^2
50 MW 1 hr.	30,000	2787	30,000	2787	17,500	1626
10 MW 8 hr.	40,000	3716	40,000	3716	22,980	2135
10 MW 1 hr.	7,000	650	7,000	650	4,000	372
50 kw 8 hr.	1,000	92.9	500	46.5	500	46.5
50 kw 1 hr.	300	27.9	200	18.6	200	18.6
10 kw 8 hr. #1,2	300	27.9	160	14.9	160	14.9
10 kw 1 hr.	75	6.97	40	3.7	40	3.7

3.5 Weight

The total weight of the rotating flywheel mass is indicated in the following table along with the number of flywheels in parenthesis.

Requirement	1980		1985		1990	
	10^3 lb	10^3 kg	10^3 lb	10^3 kg	10^3 lb	10^3 kg
50 MW 1 hr.	14,724(180)	6,679	14,724(180)	6,679	1,465(20)	665
10 MW 8 hr.	23,558(288)	10,686	23,588(288)	10,686	2,344(32)	1,063
10 MW 1 hr.	2,945(36)	1,336	2,945(36)	1,336	293(4)	133
50 kw 8 hr.	117.8(5)	53.4	10.9(5)	4.93	10.9(5)	4.93
50 kw 1 hr.	14.7(5)	6.7	1.36(5)	.62	1.36(5)	.62
10 kw 8 hr. #1,2	23.6(1)	10.7	2.17(1)	.99	2.17(1)	.99
10 kw 1 hr.	2.95(1)	1.34	.27(1)	.12	.27(1)	.12

3.6 Fuel

This system must be supplied with external electric power for charging before initial and subsequent use. The lifetime electrical cost (EC) and the average electrical cost per year are listed in the table below.

Requirement	EC x 10^3 1977 Dollars			EC/Yr x 10^3 1977 Dollars		
	1980	1985	1990	1980	1985	1990
50 MW 1 hr.	22,000	22,000	22,000	880	880	880
10 MW 8 hr.	37,292	37,292	37,292	1,492	1,492	1,492
10 MW 1 hr.	4,399	4,399	4,399	176	176	176
50 KW 8 hr.	188.1	146.1	188.1	7.52	7.30	7.52
50 KW 1 hr.	22.0	17.0	22.0	.879	.852	.879
10 KW 8 hr. #1,2	37.1	28.8	37.1	1.483	1.442	1.483
10 KW 1 hr.	4.39	3.41	4.39	.176	.171	.176

3.7 <u>Environmental Constraints</u>

The environmental constraints of the power system are indicated in the following tabulation:

X amount of uncontrolled emission

Y Amount of pollution which would be emitted with no controls

Z Degree of difficulty in meeting more strict regulations

Key: blank - none
O - minor
◐ - moderate
● - major

Emissions	X	Y	Z
Thermal Discharge (a)	-	-	-
Thermal Discharge (b)	-	-	-
Air Pollution			
CO	-	-	-
HC	-	-	-
NO_x	-	-	-
SO_x	-	-	-
Particulates	-	-	-
Noise	-	-	-
Solid Waste	-	-	-
Chemical Waste	-	-	-
Radioactive Waste	-	-	-

Notes: (a) system is air or water cooled; heat rejected directly to atmosphere.
(b) system is water cooled; heat rejected to body of water or cooling tower. Water source and/or make-up required.

3.8 Location Constraints

The locational limitations of the power system, and the degree of difficulty in overcoming these limitations are indicated in the following tabulation.

— - no difficulty

O - minor difficulty

◐ - major difficulty

● - overriding limitation

LOCATION RESTRAINT	
Water required for cooling	-
Water required for process	-
Manning required during operation	-
Fuel deliveries required	-
Adequate solar insolation required	-
Adequate wind speed required	-
Isolation from population required	-
Electricity required for charging	●

3.9 Operational Constraints

The tabulated operating characteristics are applicable to the power system as indicated.

— - Characteristic not observed in system operation

O - Characteristic has minor effect on system performance

◐ - Characteristic has moderate effect on system performance

● - Characteristic has major effect on system performance

Operational Restraint	
Efficiency reduction at part load	–
Part load capability limitation	–
Dependence on solar insolation	–
Dependence on wind consistency	–
Overload capacity limitations	–
Delayed response to rapid load changes	–
Life reduction from frequent rapid load changes	–

3.10 System Efficiency

Energy Rating	Efficiency		
	1980	1985	1990
All	.70	.70	.70

The overall system efficiency includes the efficiency of the flywhell in its supports, gear box efficiencies, and the efficiancy of the motor generator unit.

3.11 Type of System

The system type is indicated in the following tabulation:

M - mobil

T - transportable

F - fixed

Energy Rating (KWHRS)	M	T	F
All			X

No change is expected for the different time frames.

3.12 Start-up/Shutdown Times

The following table contains relevent times applicable to the flywheel systems.

Requirement	Start-up	Shutdown
All	10 sec.	10 sec.

3.13 Growth Potential

The energy storage system is partially modular in nature. As a result, incremental increases in output can be achieved fairly easily. The flywheel system could also be designed to provide very low power requirements, such as 1 kw and 100 watt levels.

3.14 Reliability

The tabulated conditions exist in the power system to the extent indicated.

— - Condition does not exist in system

O - Condition exists, but its extent is sufficiently minor as to have minimal effect on system performance or reliability

◐ - Condition exists, and its extent is sufficient to have a moderate effect on system performance or reliability

● - Condition exists and is a governing factor in determining system performance and reliability.

Conditions	
Numerous moving parts	O
High temperature operation	-
High stress levels	●
High radiation level	-
Corrosive attack	-
Thermal cycling	-
Non-modular design	◐
Solar insolation required	-
Wind required	-

3.15 Maintenance and Operation

Combined Operation and Maintenance Costs

Requirement	1980 $/Yr	1985 $/Yr	1990 $/Yr	Personnel Required Continuously
50 Mw 1 hr.	73,000	73,000	73,000	Yes
10 Mw 8 hr.	116,800	116,800	116,800	Yes
1 hr.	14,600	14,600	14,600	Yes
50 kw 8 hr.	800	800	800	No
1 hr.	150	150	150	No
10 kw 8 hr. #1, 2	160	160	160	No
1 hr.	30	30	30	No

Major maintenance would include the changing of flywheel support bearings and overhauling of the gear box and clutch.

The flywheel energy storage system should compare favorably with the maintenance of a pumped storage or hydroelectric station.

3.16 Other Energy Production

None.

3.17 Availability of Raw Building Materials

There are no critical materials required in this system.

3.18 Development

In order for flywheel energy storage systems to become more feasible in the near term, they will be dependent on the development of an industry which will be able to produce fiber composite flywheels at an attractive price. Also, advances in bearing would have to be made so that wear and energy losses in this critical area are minimized. The state-of-the-art in flywheel energy storage systems is best summarized by stating that low energy density systems of a few kw have been constructed and are being applied with great promise for success in transporation applications. The technology associated with those devices is not particularly advanced. Advanced, high energy density systems have been proposed and certain critical components, such as the wheel itself, have been built and tested on a laboratory scale. To date, a detailed system design study in which the wheel is integrated into a total, reliable system is yet to be carried out.

The following table lists industry capabilities for flywheels:

TABLE 6.

INDUSTRY CAPABILITIES FOR FLYWHEELS

Organization	Expertise
Airesearch	Input/output, containment regenerative systems
Battelle	Structures, composites, overall design
Bell Aerospace	Materials
Borg Warner	Input/output, controls
Brunswick	Wheel development
General Electronic	Input/output, wheel fabrication
Hittman Associates	Systems
Rockwell International	Systems
Sperry Flight Systems	Magnetic suspensions and Bearings
Stanford Research Institute	Wheel development
Union Carbide	Conventional bearings, wheel development, testing
University of Wisconsin	Conventional/flywheel car simulation, studies
Westinghouse Electric	Systems, wheel development

4.0 REFERENCES

1. An Assessment of Energy Storage Systems Suitable for Use by Electric Utilities, Final Report, EPRI EM-264, Project 225, ERDA (11-1)-2501, July, 1976.

2. Proceedings of the 1975 Flywheel Technology Symposium, ERDA 76-85, November, 1975.

3. The Multirim Superflywheel, Johns Hopkins University, AD/A-001081, August, 1974.

SECTION XXIII

BATTERY STORAGE (EXTERNAL)

1.0 SYSTEM DESCRIPTION

1.1 System Identification

Energy Converter/Cycle - electrochemical energy storage system where DC electrical energy is converted to chemical energy during charging of the unit and converted to DC electrical energy upon discharge.

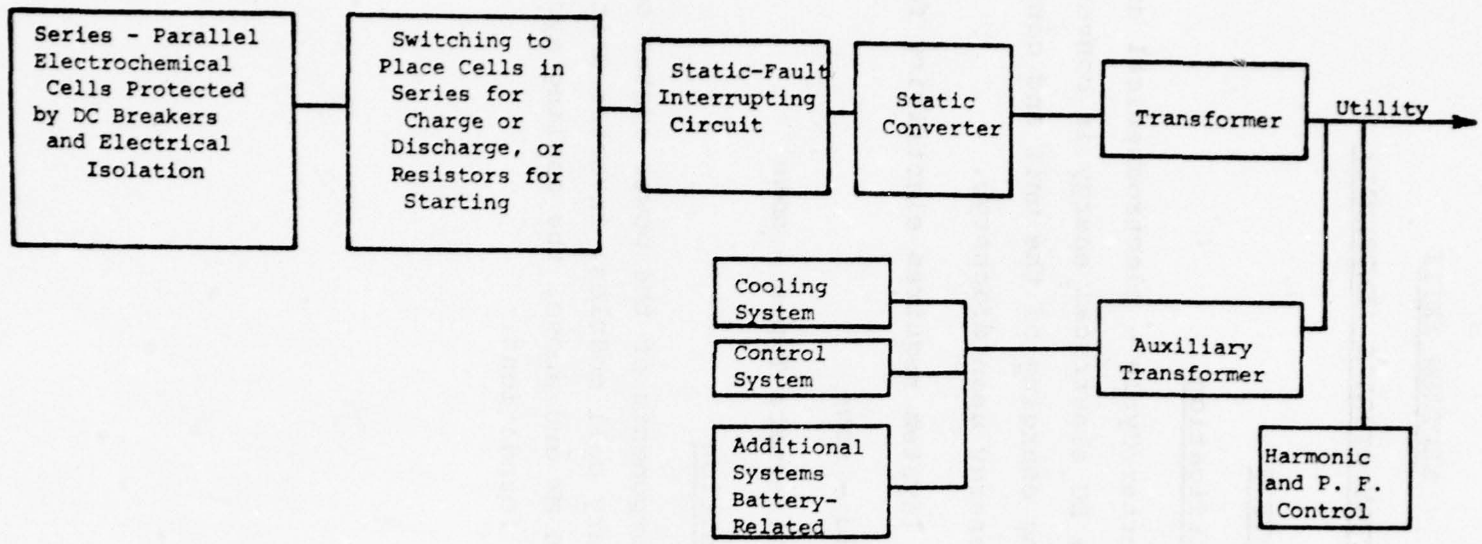
Fuel - none (system requires electricity for charging)

Working Fluid - none

Equivalent Alternate Types - none

1.2 System Definition

The major components of the power system consist of the battery cell modules, inverter unit, and for units 10 MW and above, the cooling system and housing and foundations.



BATTERY STATION CONCEPT

1.3 Physical Description

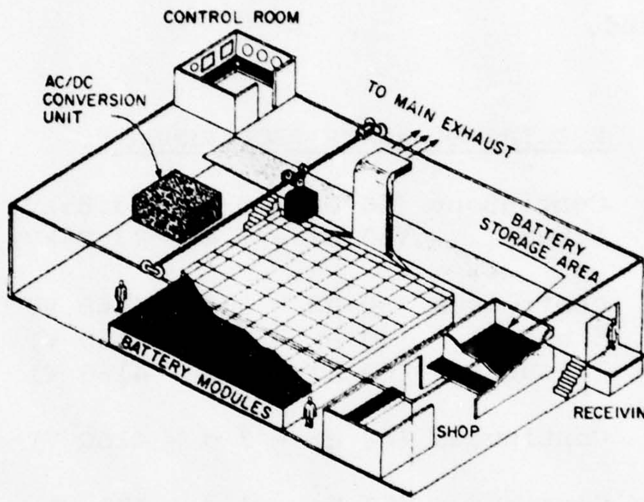


Figure 30. CONCEPTUAL 100 MW-hr LITHIUM/SULFUR BATTERY FACILITY

2.0 LIST OF REQUIREMENTS AND TIME FRAMES

This power system is applicable to the following electrical power requirements as marked. The first date listed indicates the earliest time when the system will be available for purchase. The latter date indicates the point in time when significant improvements are expected.

	ELECTRICAL POWER REQUIREMENTS	1977*	1985**
50	Continuous (60 Hz - 3 ø - 13.8 kV)	N/A	N/A
	1 hour (60 Hz - 3 ø - 13.8 kV)	X	X
10 Mw	Continuous (60 Hz - 3 ø - 4160 V)	N/A	N/A
	8 hour (60 Hz - 3 ø - 4160 V)	X	X
	1 hour (60 Hz - 3 ø - 4160 V)	X	X
750 kw	Continuous (60 Hz - 3 ø - 4160 V)	N/A	N/A
250 kw	Continuous (60 Hz - 3 ø - 480 V)	N/A	N/A
50 kw	Continuous (60 Hz - 3 ø - 480 V)	N/A	N/A
	8 hour (60 Hz - 3 ø - 480 V)	X	X
	1 hour (60 Hz - 3 ø - 480 V)	X	X
10 kw	Continuous #1 (DC - 28 V)	N/A	N/A
	Continuous #2 (60 Hz - 3 ø - 240 V)	N/A	N/A
	Continuous #3 (60 Hz - 1 ø - 240 V)	N/A	N/A
	Continuous #4 (60 Hz - 1 ø - 120 V)	N/A	N/A
	8 hour #1 (DC - 28 V)	X	X
	8 hour #2 (60 Hz - 3 ø - 240 V)	X	X
	1 hour (60 Hz - 3 ø - 240 V)	X	X

* Lead Acid Battery

** Advanced Battery

Energy storage systems, such as batteries, are not applicable to continuous power requirements.

3.0 PARAMETERS

3.1 Acquisition Cost (1977 Dollars)

Requirement	1977	1985
50 Mw 1 hr.	9,837,500	6,352,500
10 Mw 8 hr.	9,387,500	4,658,500
1 hr.	1,967,500	1,270,500
50 kw 8 hr.	30,000	17,200
1 hr.	7,700	5,600
10 kw 8 hr. #1, 2	6,000	3,500
1 hr.	1,500	1,100

3.2 Life Cycle Cost

A. The life cycle cost is defined by the following equation:

LCC = AC + OMC + EC

AC = Acquisition Cost (see Section 3.1)

OMC = Operation and Maintenance Cost Over System Lifetime (see Section 3.15)

EC = Electrical Cost Over System Lifetime (see Section 3.6)

Requirement	LCC 10^3 1977 Dollars		LCC/Year 10^3 1977 Dollars	
	1977	1985	1977	1985
50 MW 1 hr.	18,894	23,028	1,889	1,151
10 MW 8 hr.	24,798	32,906	2,480	1,645
1 hr.	3,781	4,601	378	230
50 KW 8 hr.	86.3	145	8.6	7.25
1 hr.	14.2	21.1	1.42	1.10
10 KW 8 hr. #1,2	17.4	29.47	1.74	1.47
1 hr.	2.78	4.10	.28	.21

3.3 Lifetime (years)

The useful life of the power system is indicated in the following table.

Requirement	Lifetime (Years) 1977	1985
50 Mw 1 hr.	10	20
10 Mw 8 hr.	10	20
1 hr.	10	20
50 kw 8 hr.	10	20
1 hr.	10	20
10 kw 8 hr. #1,2	10	20
1 hr.	10	20

3.4 Volume/Size

The land area occupied by the power system is indicated in the following table.

Requirement	1977		1985	
	ft^2	m^2	ft^2	m^2
50 Mw 1 hr.	25,000	2,323	2,000	185.8
10 Mw 8 hr.	40,000	3,716	3,200	297.3
1 hr.	5,000	465	400	37.1
50 kw 8 hr.	200	18.6	16	1.48
1 hr.	40	3.72	3.2	0.30
10 kw 8 hr. #1,2	40	3.72	3.2	0.30
1 hr.	40	3.72	3.2	0.30

3.5 Weight

The total weight of the battery modules is indicated in the following table.

Requirement	1977		1985	
	lb	kg	lb	kg
50 Mw 1 hr.	3,571,000	1,620,000	800,000	363,000
10 Mw 8 hr.	5,714,000	2,592,000	1,280,000	580,000
1 hr.	714,000	324,000	160,000	73,000
50 kw 8 hr.	28,600	13,000	6,400	2,900
1 hr.	3,600	1,600	800	360
10 kw 8 hr. #1,2	5,700	2,600	1,280	580
1 hr.	700	320	160	70

3.6 Fuel

This system must be supplied with external electric power for charging before initial and subsequent use. The lifetime electrical cost (EC) and the average electrical cost per year are listed in the table below.

	EC x 10^3 1977 Dollars		EC/YR x 10^3 1977 Dollars	
Requirement	1977	1985	1977	1985
50 MW 1 hr.	8,691	15,945	869.1	797.3
10 MW 8 hr.	14,826	27,079	1482.6	1,354.0
1 hr.	1,740	3.184	174.0	159.2
50 KW 8 hr.	74.4	136.1	7.44	6.85
1 hr.	9.22	17.41	.922	.875
10 KW 8 hr. #1,2	15.07	27.66	1.507	1.383
1 hr.	1.87	3.44	.187	.172

3.7 <u>Environmental Constraints</u>

The environmental constraints of the power system are indicated in the following tabulation:

X amount of uncontrolled emission

Y Amount of pollution which would be emitted with no controls

Z Degree of difficulty in meeting more strict regulations

Key: blank - none
0 - minor
◐ - moderate
● - major

Emissions	X	Y	Z
Thermal Discharge (a)	0	-	-
Thermal Discharge (b)	-	-	-
Air Pollution			
CO	-	-	-
HC	-	-	-
NO_x	-	-	-
SO_x	-	-	-
Particulates	-	-	-
Noise	-	-	-
Solid Waste	-	-	-
Chemical Waste	-	-	-
Radioactive Waste	-	-	-

Notes: (a) system is air or water cooled; heat rejected directly to atmosphere.
(b) system is water cooled; heat rejected to body of water or cooling tower. Water source and/or make-up required.

3.8 Location Constraints

The locational limitations of the power system, and the degree of difficulty in overcoming these limitations are indicated in the following tabulation.

— - no difficulty

O - minor difficulty

◐ - major difficulty

● - overriding limitation

LOCATION RESTRAINT	
Water required for cooling	-
Water required for process	O
Manning required during operation	-
Fuel deliveries required	-
Adequate solar insolation required	-
Adequate wind speed required	-
Isolation from population required	-
Electricity required for charging	●

3.9 Operational Constraints

The tabulated operating characteristics are applicable to the power system as indicated.

— - Characteristic not observed in system operation

O - Characteristic has minor effect on system performance

◐ - Characteristic has moderate effect on system performance

● - Characteristic has major effect on system performance

Operational Restraint	
Efficiency reduction at part load	-
Part load capability limitation	-
Dependence on solar insolation	-
Dependence on wind consistency	-
Overload capacity limitations	-
Delayed response to rapid load changes	-
Life reduction from frequent rapid load changes	-

3.10 System Efficiency

The power system efficiency is indicated in the following tabulation.

Requirement	Efficiency	
	1977	1985
All	.65	.75

System efficiencies are based on 80-percent battery efficiencies and line commutated converter full-load one-way efficiencies of 95 percent.

3.11 Type of System

The system type is indicated in the following tabulation.

M - Mobil

T - Transportable

F - Fixed

Time - Time for assembly or construction, hours

Requirement	1977				1985			
	M	T	F	Time	M	T	F	Time
50 Mw 1 hr.			X				X	
10 Mw 8 hr.			X				X	
1 hr.			X			X		
50 kw 8 hr.		X		168	X			168
1 hr.	X			8	X			8
10 kw 8 hr. #1,	X			8	X			8
1 hr.	X			8	X			8

3.12 Start-up/Shutdown Times

The start-up and shutdown time for the power system is indicated in the following tabulation.

Requirement	Start-up Time (Seconds)	Shutdown Time (Seconds)
All	1/2	1/2

3.13 Growth Potential

The energy storage system is modular in construction. As a result, incremental increases in output can be easily achieved. In addition, battery systems could be designed to provide very low power requirements, such as 1 kw and 100 watt levels.

3.14 Reliability

The tabulated conditions exist in the power system to the extent indicated.

— - Condition does not exist in system

O - Condition exists, but its extent is sufficiently minor as to have minimal effect on system performance or reliability

◐ - Condition exists, and its extent is sufficient to have a moderate effect on system performance or reliability

● - Condition exists and is a governing factor in determining system performance and reliability.

Conditions	
Numerous moving parts	-
High temperature operation	O
High stress levels	-
High radiation level	-
Corrosive attack	O
Thermal cycling	-
Non-modular design	-
Solar insolation required	-
Wind required	-

3.15 Maintenance and Operation

The annual combined maintenance and operating costs for the power system are listed in the following tabulation.

Requirement	Operation and Maintenance Cost 1977 $/Year 1977	1985	Personnel Required Continuously
50 Mw 1 hr.	36,500	36,500	No
10 Mw 8 hr.	58,400	58,400	No
1 hr.	7,300	7,300	No
50 kw 8 hr.	400	400	No
1 hr.	100	100	No
10 kw 8 hr. #1, 2	80	80	No
1 hr.	20	20	No

3.16 Other Energy Production

None.

3.17 Availability of Raw Building Materials

Lead could be a critical material for lead acid battery systems.

3.18 Development

For the near term, battery research and development efforts should be geared toward design and production engineering to apply state-of-the-art technology. For the long term, major research programs should be directed at the key problem of attaining adequate life under cycling conditions and developing inexpensive and simple fabrication procedures. Early consideration should include cost engineering studies, complete cell and module designs, and extensive cell experimental work.

A considerable effort in a joint ERDA, EPRI, and utility study of the feasibility of a battery energy storage test facility has concluded that centralized testing of prototype battery cells and modules of essentially commercial scale are feasible and will permit large-scale testing of advanced batteries in the early 1980's.

Under contracts with Argonne National Laboratories, three firms - Gould, Inc.; Eagle-Picher Industries, Inc.; and Catalyst Research Corporation - are developing manufacturing procedures and fabricating of lithium/iron sulfide test cells. In addition, the Atomics International Division of Rockwell International is conducting a more general research and development program under a contract to Argonne National Laboratories. In the area of material components, Carborundum Corporation, the University of Florida (funded directly by ERDA), Fiber Materials, Inc., and Zircar Products, Inc., are fabricating paper and felt electrode separators. Ceramaseal, Inc., and Coors Porcelain are developing electrical feedthroughs and insulators.

4.0 REFERENCES

1. AN ASSESSMENT OF ENERGY STORAGE SYSTEMS SUITABLE FOR USE BY ELECTRIC UTILITIES, FINAL REPORT, EPRI EM-274, PROJECT 225, ERDA(11-1)-2501; July, 1976

2. SPACE BATTERIES, NASA SP-5004

3. BATTERIES FOR SPACE POWER SYSTEMS, NASA SP-172

4. COST ESTIMATE FOR THE COMMERCIAL MANUFACTURE OF LITHIUM/IRON SULFIDE CELLS FOR LOAD LEVELING; W. L. Towle, J. E. Graae, A. A. Chilenskas, and R. O. Ivins; Argonne National Laboratory; ANL-76-12; March, 1976

5. DEVELOPMENT PROGRAM FOR SOLID ELECTROLYTE BATTERIES, FINAL REPORT, EPRI EM-226, PROJECT 127; September, 1976

6. ANNUAL REVIEW OF ANL BATTERY PROGRAM; Argonne National Laboratory; U of C-AVA-USERDA; March, 1977

7. NATIONAL ELECTRIC RATE BOOK of the Federal Power Commission.

APPENDIX A

FUEL COSTS AND RESOURCE AVAILABILITY

This Appendix presents the costs which were assumed for the various fuels considered in this report and the cost of electricity required for the energy storage systems. Also included are maps which show the geographical variations in energy available from the sun and wind throughout the United States. The fuel costs given here are employed to determine the average annual fuel costs which are tabulated in Section 3.6 of each chapter of the Energy Conversion Systems Handbook. The electricity costs given in this Appendix are employed to determine the average annual electrical power costs which are tabulated in Section 3.6 of the chapters of the Energy Conversion Systems Handbook which cover the energy storage systems.

The assumed costs for fossil fuels are given in Table A-I and are expressed in terms of a cost per energy unit for the year 1977 and an annual differential escalation rate. The annual differential escalation rate is the anticipated annual escalation resulting from factors unique to the fuel market over and above the escalation experienced by the economy as a whole. The average annual fuel costs which are tabulated in Section 3.6 of each chapter of the Energy Conversion Systems Handbook are calculated by dividing the cost of the fuel consumed over the system's life by the lifetime (see Section 3.3 of each chapter) of the system. The following procedure can be used when the same amount of fuel is consumed each year.

TABLE A-I

1977 COSTS OF FOSSIL FUELS AND ANNUAL DIFFERENTIAL ESCALATION RATES

	1977 Cost per million Btu	Annual Differential Escalation Rate
No. 2 Distillate Oil	$2.73	2.3%
Natural Gas	$1.29	2.3%
Naphtha	$3.36	*
Coal (high or low sulfur)	$0.95	1.0%

* Naphtha cost assumed to exceed cost of No. 2 Distillate oil by $0.63 per million Btu each year.

1. Determine the fuel cost basis for the initial year of plant operation by the formula

$$C_i = C_{77}\,(1+\varepsilon)^y \qquad A(1)$$

where C_i is the fuel cost per energy unit at the start of plant operation, C_{77} is the fuel cost per energy unit in 1977 as given in Table A-I, ε is the annual differential escalation rate for the fuel (also given by Table A-I) and y is the number of years beyond 1977 when the system is assumed to begin operation. In all cases, the initial year of operation is assumed to be the first year in which the technology is expected to become available.

2. Determine the average annual fuel cost per energy unit over the lifetime of the system by the formula

$$C_T = \frac{C_i}{n}\,\frac{(1+\varepsilon)^n - 1}{\ln(1+\varepsilon)} \qquad A(2)$$

where C_T is the total fuel cost over n years and n is the system lifetime expressed in years.

3. Determine the average annual fuel cost by multiplying the average annual fuel cost per energy unit by the number of energy units consumed per year.

As an example, consider a system which is expected to first become technologically available in 1985. This would be the date which is indicated at the top of one of the columns in the various tables in the chapter of the Energy Conversion Systems corresponding to that system. If the system uses No. 2 distillate oil as a fuel, the cost per Btu of that fuel in 1985 would be $C_i = 2.73 \times (1.023)^8 = \$3.27$ per

million Btu according to Table A-I and Equation A(1). If this system has a lifetime of 30 years, then the average annual fuel cost per Btu would be

$$C_A = \frac{\$3.27}{30} \frac{(1.023)^{30} - 1}{\ln(1.023)} = \$4.70$$

per million Btu according to Equation A(2). If the system consumes fuel at a rate of 10,000 million Btu per year, then the average annual fuel cost would be 10,000 x 4.7 =$47,000 per year. This cost is in 1977 dollars since the escalation rate used is an annual differential escalation.

Equation A(2) is derived on the basis that the fuel cost escalates continuously throughout each year. If the fuel cost increases once per year or if it is purchased by contract at the beginning of each year, the appropriate formula would be

$$C_A = \frac{C_i}{n} \frac{(1+\varepsilon)^n - 1}{\varepsilon} \qquad A(3)$$

For small escalation rates, the difference between the results for equations A(2) and A(3) is very small.

The cost estimate for No. 2 distillate oil is based upon data from two independent sources. The estimates for 1977 distillate oil costs determined from these two sources were very close. Exhibit II-14 of Reference A.1 shows a distillate oil price of $2.40 per million Btu for 1975 with a 2.3% annual differential escalation rate. To determine the corresponding 1977 fuel cost in 1977 dollars requires escalating the 1975 costs over a two year period at the actual annual escalation rate. The actual annual escalation rate would be the combination of the differential annual escalation rate

and the rate of escalation of the economy as a whole. For an annual differential rate of 2.3% and a general escalation rate of 5%, the combined escalation rate would be 7.4%. This yields a 1977 fuel cost of $2.77 per million Btu.

Reference A.2 gives records of fuel contracts during the month of March 1977. The average of 82 deliveries of No. 2 distillate fuel oil from this source is $2.73 per million Btu. This cost was assumed for all cases in the Energy Conversion Systems Handbook. The annual differential escalation rate assumed for all cases was the 2.3% rate taken from Reference A.1.

Natural gas prices for 1977 were obtained from Reference A.2 by determining the average price of 137 natural gas deliveries during the month of March 1977. The result is $1.29 per million Btu. The annual differential escalation rate for natural gas was assumed to be the same as that for No. 2 distillate oil: 2.3%. The cost assumed for naphtha is based upon data given in Exhibit II-14 of Reference A.1 which indicates a cost for naphtha of $.63 per million Btu above that of No. 2 distillate fuel oil for every year under consideration. Thus, the cost for naphtha is assumed to be $3.36 per million Btu in 1977.

Exhibit II-9 of Reference A.1 is a Table which gives delivered coal prices for various regions of the U.S. for the year 1975 as well as projected delivered cost prices for the year 2000. This exhibit did not give coal consumption rates for the various regions. However, an unweighted national average was obtained by summing the prices for the various regions and dividing by the number of regions included in the sum. The 1975 average coal prices determined by

this procedure were \$.86 per million Btu for low-sulfur coal and \$.84 per million Btu for high-sulfur coal. The coal prices projected for the year 2000 are in 1975 dollars and are \$1.09 per million Btu for low sulfur coal and \$1.10 per million Btu for high sulfur coal. This represents an annual differential escalation rate of approximately 1% for both types of coal. Neglecting the differences between low-sulfur and high-sulfur coal prices, a 1977 coal price of \$.95 per million Btu is established by a two-year escalation of the 1975 price by a 5% annual rate for general escalation and a 1% annual rate for differential escalation.

Establishing the nuclear fuels costs is considerably more involved than establishing the costs of fossil fuels since the nuclear fuel cost involves costs of uranium ore, conversion and enrichment of the uranium, fabrication of fuel elements, reprocessing or waste disposal, and possibly a credit for uranium and plutonium after reprocessing. The cost is also dependent upon the refueling cycle, the burnup rate and the enrichment differential between the time of fuel assembly installation and the time of fuel assembly replacement. Thus, the basis for the fuel cost can vary from system to system. However, since the accuracy of the costs would not warrant such detail, nuclear fuel costs were established under one set of assumptions as indicated in Table A-II. The resulting costs are given in Table A-III and are used for all nuclear/fission systems. As a word of caution, it must be noted that capital charges and present worth factors have been omitted from the calculations of nuclear fuel costs to be consistent with the method of calculating life cycle costs as explained in Section 3.2 of the Handbook Guide portion of the Energy Conversion Systems Handbook.

TABLE A-II

NUCLEAR FUEL COST ASSUMPTIONS

Reactor Fuel Cycle

Power - electrical	-	50 MWe
Thermal	-	150 MW_T

Refueling Cycle - 3 years

Average discharge burnup - 64000 MWD/MTU

Enrichment - initial	-	8.2% U235
final	-	1.0% U235
Capacity Factor		80%

Unit Prices (base January 1977)

Uranium	$30/KgU
Conversion	$ 3/KgU
Enrichment	$75/SWU
Fabrication	$200/KgU
Reprocessing or Waste Disposal	$200/KgU
Uranium Credit, Plutonium Credit	considered in reprocessing cost

SCHEDULE

U purchase	1.25 years before insertion
Conversion	1.25 years " "
Enrichment	0.75 years " "
Fabrication	0.50 years " "
Reprocessing or Waste disposal	2.00 years after discharge
Reactor start-up	January 1, 1985
Economic life	40 years

TABLE A-III

ANNUAL LEVELIZED NUCLEAR FUEL COSTS

Year	Cost Mills/KWH	Year	Cost Mills/KWH
1985	5.99	2005	7.16
1986	5.99	2006	7.38
1987	5.99	2007	7.38
1988	6.17	2008	7.38
1989	6.17	2009	7.60
1990	6.17	2010	7.60
1991	6.36	2011	7.60
1992	6.36	2012	7.83
1993	6.36	2013	7.83
1994	6.55	2014	7.83
1995	6.55	2015	8.07
1996	6.55	2016	8.07
1997	6.75	2017	8.07
1998	6.75	2018	8.32
1999	6.75	2019	8.32
2000	6.95	2020	8.32
2001	6.95	2021	8.57
2002	6.95	2022	8.57
2003	7.16	2023	8.57
2004	7.16	2024	8.83

This omission yields nuclear fuel costs which may differ considerably from the costs which would be employed by other sectors of the economy such as the electric utility industry.

Electric power costs for the energy storage systems are subdivided into demand charges and energy charges. The demand charge is based upon the power level (kw) at which the electricity is delivered to the energy storage system. The energy charge is based upon the annual electrical energy (kwhr per year) delivered to the energy storage system. On the basis of data accumulated from Reference A.3, an average demand charge for the U.S. is taken to be $38.68 per kw per year. A portion of the energy charge is attributed to the fuel which is consumed during the production of the electric power. This portion is thus escalated at a rate comparable to the fuel escalation rates. From data accumulated from Reference A.3, an average energy charge for the U.S. is taken to be 25 mills/kwhr in 1977. It is assumed that 50% of this is attributed to fuel costs with an annual differential escalation rate of 2.3%, the same rate assumed for oil and natural gas. Thus, the energy charge is a fixed 12.5 mills per kwhr plus an additional amount which escalates at 2.3% starting at 12.5 mills per kwhr in 1977.

Figure A-1 is a map of the United States showing the distribution of availability of wind power. Contours are shown indicating valuesof constant annual average wind power density. The power density is the wind power power per unit cross sectional area of the wind turbine and is expressed in watts per square meter. The data given in Chapter XIX of the Handbook correspond to regions with annual average wind power

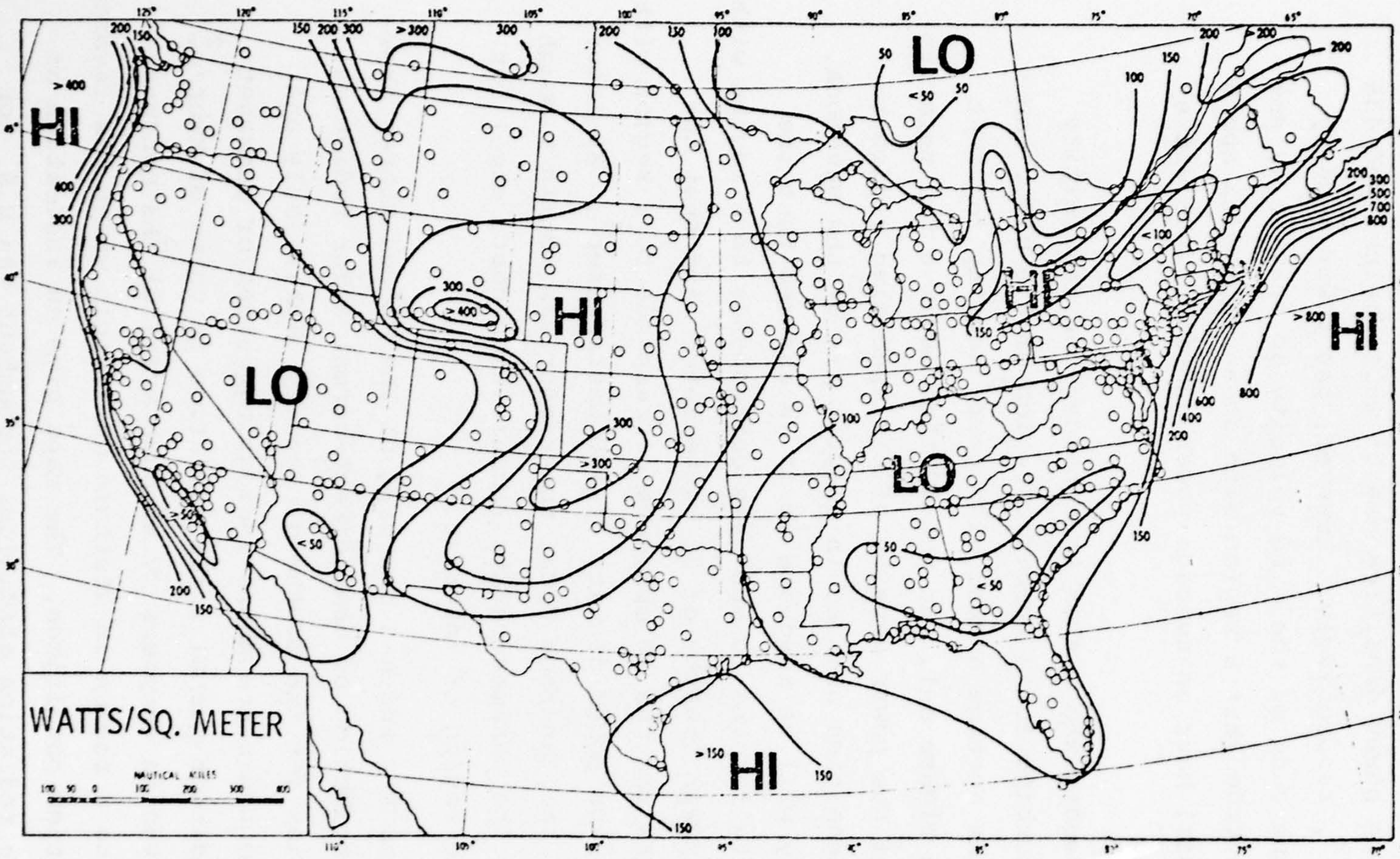
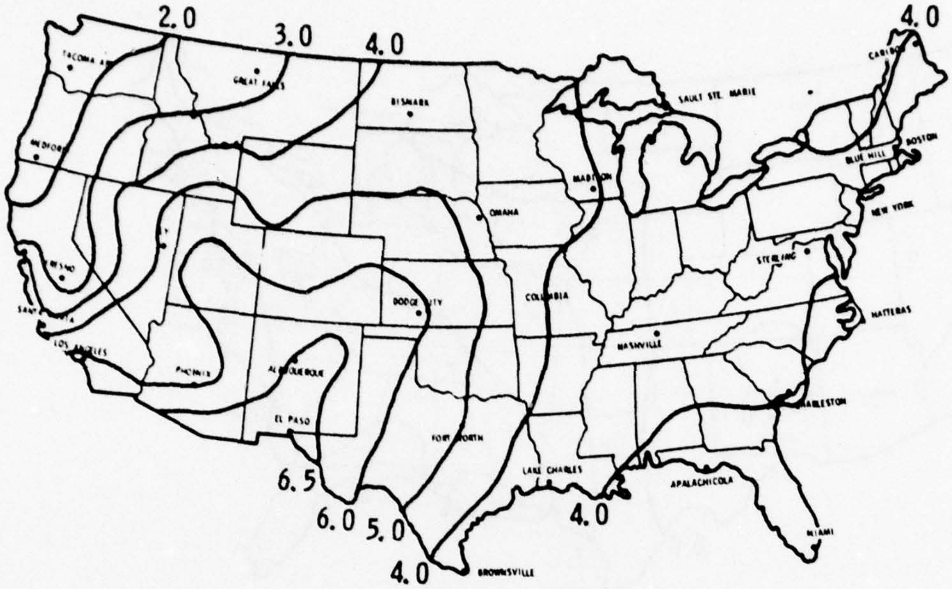


FIGURE A-1 AVAILABLE WIND POWER - ANNUAL AVERAGE (REFERENCE A.4)

corresponding to wind speeds of 10 mph and 20 mph. The corresponding power densities are 55 watts/meter^2 and 438 watts/meter^2, respectively. However, the power density varies as the cube of the wind velocity so that it is not necessarily true that a region with an average wind speed of 10 mph will have an average power density of 55 watts/meter^2.

The reader who wishes to consider the feasibility of a wind turbine for a specific region of the U.S., can determine the average annual wind power density for that region from Figure A-1. He should then observe the relative magnitude of the power density of his specified region to the power densities assumed in Chapter XIX of the Handbook. The accuracy will be adequate if it is assumed that the Handbook data for the 10 mph case corresponds to a region with an average power density of 50 watts/meter^2 and that the Handbook data for the 20 mph case corresponds to a region with with an average power density of 400 watts/meter^2. By interpolation of the Handbook data, the reader can obtain a rough estimate of the parameter data (acquisition cost, etc.) for the specific region of interest.

Figures A-2 and A-3 are maps of the United States showing the distribution of mean direct-normal solar radiation availabilities for the months of January, April, July and October. Contours are shown indicating values of constant mean daily direct-normal solar radiation in units of kwhr/m^2. The data given in chapters XV through XVIII of the Handbook correspond to a region in Southern California which has favorable solar radiation conditions. The maps give an indication of the relative radiation conditions throughout the U.S. for



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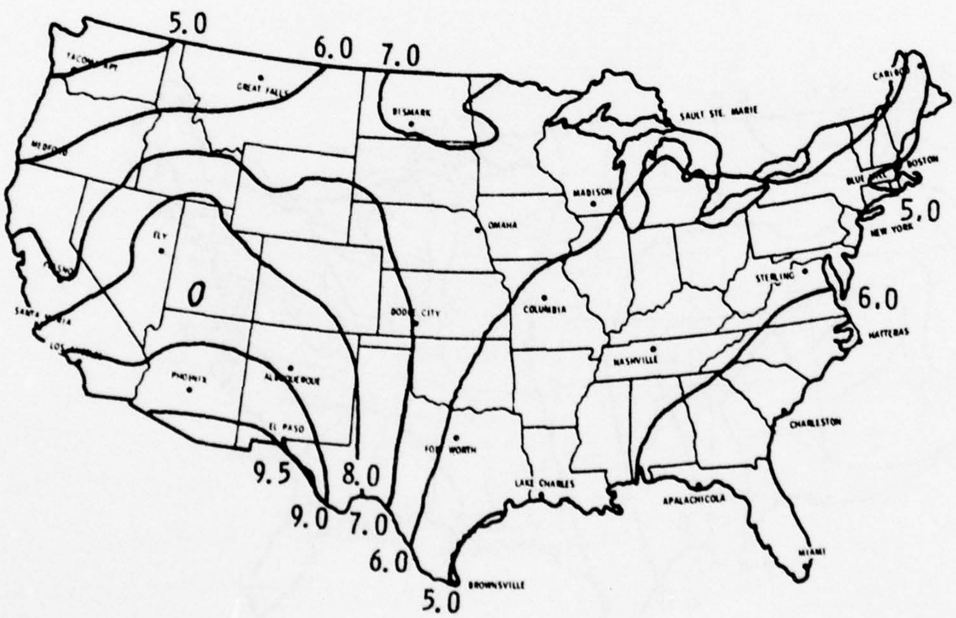

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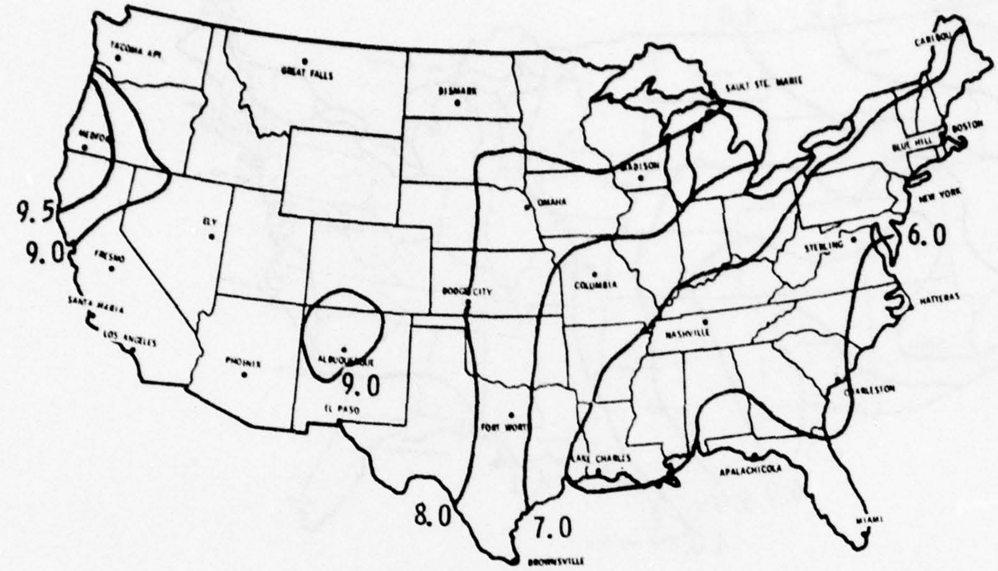
FIGURE A.2 - Mean Daily Direct Normal Solar Radiation ($kwhr/m^2$) for January and April (Ref. A.5)



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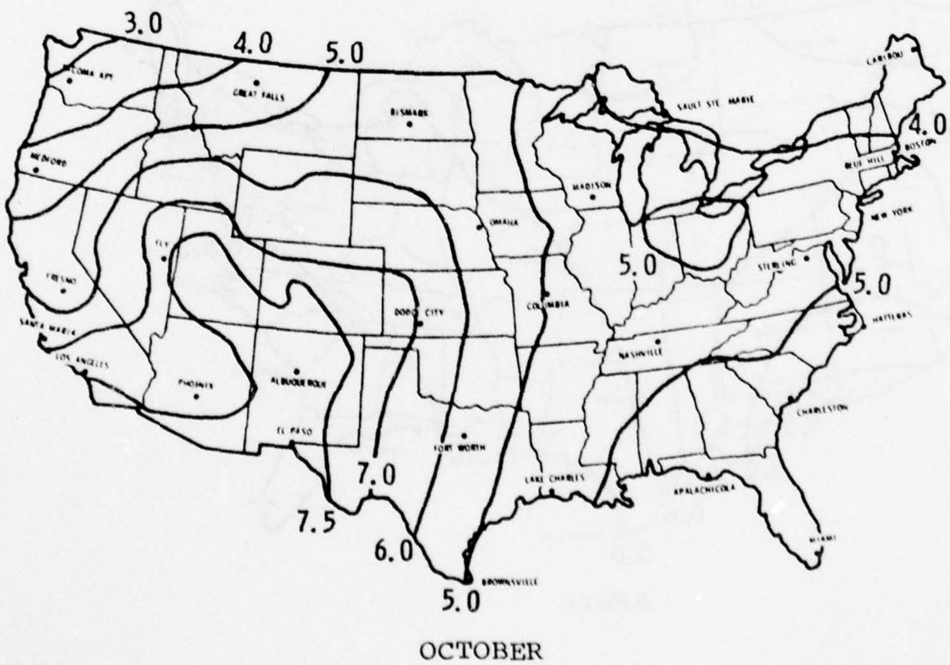

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FIGURE A.3 - Mean Daily Direct Normal Solar Radiation ($kwhr/m^2$) for July and October (Ref. A.5)

direct-normal radiation, as appropriate for concentrating tracking collectors. However, a detailed analysis of solar data is required in order to establish parameter (e.g. acquisition cost, etc.) values for solar-energy systems for any specific region of the U.S.

References

A.1 Comparing New Technologies for the Electric Utilities 12/9/76, U.S. Energy Research and Development Administration, ERDA 76-141 (Discussion Draft).

A.2 Electrical Week, McGraw-Hill, July 4, 1977.

A.3 National Electric Rate Book, Federal Power Commission.

A.4 Weatherwise, December 1974, pg. 240.

A.5 E. C. Boes, I. J. Hall, R. R. Praire, R. P. Stromberg, H. E. Anderson, Distribution of Direct and Total Solar Radiation Availabilities for the U.S.A., Sandia Laboratories, SAND 76 - 0411.

APPENDIX B

ALTERNATE LIFE CYCLE COSTING METHOD

B.1 - Introduction

The method which was employed for determining the life cycle cost of the systems is described in Section 3.2 of the Handbook Guide portion of the Energy Conversion Systems Handbook. The method employed was to take the straight sum of all the costs incurred over the life of the system without regard to the time at which each individual expenditure is to be made. That is, the life cycle cost was determined by the formula

$$LCC = AC + FC + OMC$$

where AC is the acquisition cost in 1977 dollars, FC is the cumulative payments for fuel over the system lifetime and OMC is the cumulative costs of operation and maintenance over the life of the system. Since the lifetimes of the various systems differ from one another, the ratio of the life-cycle cost to the system lifetime is also tabulated in the Handbook. Escalation was not included except for annual differential escalation rates for fuel above and beyond the rate of escalation of the economy as a whole. The method employed in the Handbook for determining the fuel cost is described in Appendix A.

The attractive feature of this method is its simplicity. However, the simplicity itself introduces several shortcomings due to the omission of consideration of several factors. The factors which are omitted from consideration include the time value of money associated with the interest rate or discount rate, the differences in the lifetimes of the various systems, the differences in the dates of initial availability of the various systems and the differences in the construction times

for the various systems. The omission of factors such as these effect not only the accuracy of the results, but can influence the relative rankings of systems which are being compared with one another.

There are a number of alternate economic analysis procedures which can be employed which do take into account the factors which were omitted from consideration in the preceding method. This appendix describes one such method. This is based upon procedures and guidelines which are employed by U.S. Government agencies, including the U.S. Air Force for investment analysis in energy conservation projects. Such a method is presented in References B.1 and B.2 and portions of it which are appropriate to this study are outlined below.

B.2 - Present Value and Discounting

The Office of Management and Budget (OMB) has specified that a 10 percent annual interest rate be used to discount investment decisions for funds used by the United States Treasury. Use of this discount rate accounts for the loss of opportunity to earn money from investment of the same funds elsewhere. In order to put payments which are made at different time periods on a common basis, the present value concept is employed. The present value of a payment to be made several years from now is the amount of money which would have to be invested at the present time to yield the desired amount in the specified future year. For example, an investment of \$1000 at an annual interest rate of 10% would yield $\$1000 \times (1.1)^5 = \$1,611$ in five years. Thus the "present value" of a payment of \$1,611 in five years is \$1000 at a discount rate of 10%. Similarly, a series of payments over a period of several years can have a present value. For example, a series of three equal payments of \$500 per year over a period of three years (beginning at the end of the first

year) would have a present value of $\$500 \div (1.1) + \$500 \div (1.1)^2 + \$500 \div (1.1)^3 = \$1243$ when the discount rate is 10%.

B.3 - Present Value with Differential Escalation

If the cost of an item is expected to escalate at the rate experienced by the economy as a whole, the procedures indicated in Section B.2 can be employed and the present values will be in current dollars. If the costs of certain items (such as fuel) are expected to escalate at a faster rate than the economy as a whole, the present value in current dollars is determined by using the differential escalation rate. For example, if a fuel is expected to have a 3 percent annual differential escalation rate, an amount of fuel which costs \$1000 today will cost $\$1000 \times (1.03)^5 = \$1159$ in five years If the annual discount rate is 10 percent, the current present value of a payment of \$1159 in five years is $\$1159 \div (1.10)^5 = \$720$ in current dollars.

This approach can be applied to the life cycle cost determination of the energy conversion systems. Consider a system which will require three years for construction and has an economic life (after construction) of 15 years. The acquisition cost payments may be distributed over the three-year construction period. For example, assuming zero differential escalation for equipment and construction, a total of \$75,000 might be payed out in three equal payments of \$25,000 at the end of each of the first three years. The present value of the acquisition cost in current dollars would be $\$25,000 \times ((1.1)^{-1} + (1.1)^{-2} + (1.1)^{-3}) = \$62,171$. If the operating and maintenance costs have zero differential escalation and require equal annual payments of \$3,000 per year for the entire 15-year economic life, the present value of the total operating and maintenance cost would be $\$3,000 \times ((1.1)^{-4} + (1.1)^{-5} + \ldots + (1.1)^{-18}) = \$17,144$ assuming payments at the end of each year of operation. If the fuel cost

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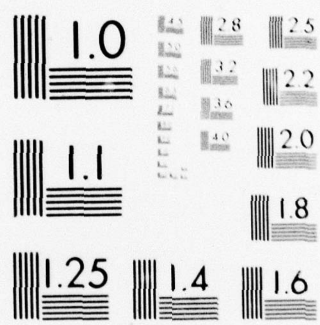

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has a 3 percent differential escalation and if the same amount of fuel is consumed each year (equivalent to \$3,000 worth of fuel per year at today's prices) the present value of the fuel cost would be $\$3,000 \times ((1.03/1.10)^3 + (1.03/1.10)^4 + \ldots + (1.03/1.10)^{17}) = \$24,269$ assuming payments at the beginning of each year of operation.

B.4 - Comparison of Systems with Different Economic Lifetimes

The present values determined from the procedure described above can be used for comparison of systems with equal economic lifetimes. However, if the lifetimes are different, some modifications to the procedure are required. One approach for comparing two systems with different economic lifetimes, is to consider an economic analysis period which is the same as that of the system with the shorter life. Then the system with the longer economic life will have a "residual value" at the end of the economic analysis period. The actual salvage value of the latter system at the end of the period may not be a realistic value since the system may have greater economic value if it were to continue operating at the original installation than if it were to be treated as salvage. A more appropriate residual value might be obtained by multiplying the acauisition cost by the ratio of the number of years of life remaining to the economic life of the system. For example, if one system has an economic life of 8 years and the other has an economic life of 12 years, the economic analysis period would be 8 years (assuming procurement of a system requiring no construction period). Then the longer-life system would have four years of life remaining out of an original life of 12 years, representing one-third of its life remaining. If the acquisition cost is \$75,000, the residual value would be 1/3 of \$75,000 = \$25,000. The present value of the residual value would be $\$25,000 \div (1.1)^8 = \$11,663$ which would be taken as a credit for the longer-life system.

Another method of comparing two systems with different economic lifetimes is to assume that the system with the shorter lifetime is replaced at the end of its life. The economic analysis period would then extend to the end of the life of the system with the longer economic life. If the system which replaced the original system still has usefulness at the end of the economic analysis period, its "residual value" can be established in the same manner as in the preceding example.

B.5 - Comparison of Systems Reaching Technological Feasibility in Different Years

Many of the systems considered in this study are not currently available. Caution must be employed in comparing systems with different starting dates because the present values of the life cycle costs depend upon the time period over which expenditures are to be made. A system starting operation in the future should not be compared with a system starting operation at the present time by simply comparing the life cycle cost present values. The purpose of life cycle costing is to provide a basis for decision making. When considering an advanced system which is not expected to be available until, say, 1985, it may be presumed that it is being considered for an installation which does not require a power supply until 1985. Then the decision which must be made is whether to select that advanced system or any other system which would be available before 1985 assuming that all systems being compared would be installed in 1985. Thus, the economic period which should be considered for present-value analysis should be the same for all systems which are being compared. As an example, suppose an application is being considered in which a power supply is required in the year 1987. A comparison can be made of all systems which would be available

before 1987 (allowing time for construction). However, it should be assumed that all systems begin operation in 1987. Cases in which it is meaningful to compare a system starting operation in one year with another system starting operation in a different year may occur in industries seeking revenues from the sale of electric power. However, such cases are not likely to occur in U.S. Air Force ground power applications.

B.6 - Summary

The procedures described in this appendix are intended to give an indication of the types of considerations which must be included in a thorough economic comparison of energy conversion systems for use by the U.S. Air Force. The user of this Handbook may employ these techniques or he may make simplifying assumptions or he may use more sophisticated techniques dependent upon the need for accuracy and the level of accuracy assumed in the original data such as acquisition costs, fuel costs, differential escalation rates and so forth.

References

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